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LECTURES

DELIVERED TO THE

EMPLOYES

OF THE

Baltimore and Ohio Railroad Company

BY

PROF. H. NEWELL MARTIN,
Of the Johns Hopkins University,

AND

DRS. HENRY SEWALL, WM. T. SEDGWICK AND WM. K. BROOKS,
Associate Instructors in the Biological Department of the University.

FOR FREE DISTRIBUTION AMONG THE EMPLOYES OF THE BALTIMORE
AND OHIO RAILROAD COMPANY.

BALTIMORE
PRINTED AND LITHOGRAPHED BY ISAAC FRIEDENWALD.
1882.

IN accordance with the following circular, which was extensively distributed among the employes of the Baltimore and Ohio Railroad Company, a course of four lectures, now printed in pamphlet form, was delivered in Baltimore in the month of February, 1882:

LECTURES

For the Employes of the Baltimore and Ohio Railroad Company.

A course of Free Lectures, specially designed for employes of the Baltimore and Ohio Railroad Company, will be delivered in the month of February by Professor H. Newell Martin, of the Johns Hopkins University, and the Associate Instructors in the Biological Department of the University, as follows:

Friday, February 3—Prof. H. NEWELL MARTIN:
How Skulls and Backbones are Built.

Friday, February 10—DR. HENRY SEWALL:
How We Move.

Friday, February 17—DR. WM. T. SEDGWICK:
On Fermentation.

Friday, February 24—DR. WM. K. BROOKS:
Some Curious Kinds of Animal Locomotion.

These Lectures will be delivered in Hollins Hall, corner of Hollins street and Carrollton avenue, at 8 P. M., on the dates named. All employes of the Baltimore and Ohio Railroad Company are cordially invited.

The privilege of attending these Lectures is also extended to the wives and daughters of employes of the Company.

Tickets for admission to the course of Lectures can be obtained from

MR. A. J. FAIRBANK, General Agent, Camden Station.
MR. CASPAR HUSSELL, Foreman, Bailey's.
MR. L. F. BEELER, General Agent, Locust Point.
MR. E. L. MCCAHAN, Time Keeper, Riverside.
MR. E. E. SHELDON, at the Library Room, Mount Clare, from 12 to 1 P. M. daily.

JOHN W. GARRETT,
President.

Reclass 11-11-34 MZ

Mr. Garrett was present on each occasion and introduced the lecturers.

At the conclusion of the last lecture, which was delivered on Friday, February 24th, 1882, Mr. John N. Conway, foreman of the Company's foundry at Mount Clare, Baltimore, offered the following resolution, which was unanimously adopted:

Resolved, That the acknowledgments of the employes of the Baltimore and Ohio Railroad Company are due, and are hereby tendered, to Mr. John W. Garrett, President, for the kindly interest he has manifested in their behalf in connection with the course of Free Lectures arranged for them by him in the month of February, 1882; and that they desire also to express their acknowledgments to Prof. H. Newell Martin, of the Biological Department of the Johns Hopkins University, and the Associate Instructors in that Department, Drs. Henry Sewall, Wm. T. Sedgwick and Wm. K. Brooks, for their kindly co-operation, and for the practical and interesting lectures which they have delivered.

President Garrett was called for, and, after the applause with which he was greeted had subsided, said:

My Friends:

When the suggestion was made that lectures of this character might prove interesting and entertaining to the employes of the Baltimore and Ohio Railroad Company and their families, it was hoped that result would be realized. It is, therefore, very agreeable to the President of the Company to join the employes in their acknowledgments to Prof. Martin and his Associates for the very interesting lectures which they have delivered.

The President has the pleasure of stating that these gentlemen have consented to prepare their lectures, which will be printed in pamphlet form, and distributed to all of you who may desire to read and study them.

It is hoped, as these lectures have been so well attended and so thoroughly appreciated, that on other occasions, and in other seasons, arrangements can be made for a similar character of lectures, or those of a like entertaining and instructive nature, and that they may hereafter be regarded as a feature connected with the service of the Baltimore and Ohio Railroad Company.

I am happy to say that many celebrated lecturers, among others the eminent traveller, Mr. Paul du Chaillu, have offered their services in connection with the course of lectures to the employes of the Company.

This pamphlet is printed by Mr. Garrett for free distribution among the employes of the Baltimore and Ohio Railroad Company. Copies can be secured by written or personal application at the President's office in Baltimore.

INTRODUCTORY NOTE.

The delivery of the lectures printed on the following pages had an almost accidental origin. In the course of a conversation one evening with President J. W. Garrett, the reading room at Mount Clare Works, which was established in December, 1869, and in which there are about 1000 volumes selected for the advantage of the employes of the Baltimore and Ohio Railroad Company, and the reading room at Canton, came under discussion. At these rooms the current newspapers and magazines are provided for the intellectual recreation of those citizens whose daily work is more with hand than head, and whose incomes are such as to make the purchase of more than a small number of books impracticable. In consequence of the generosity of Mr. Enoch Pratt, every Baltimorean will in future have the opportunity to read at home any standard work which he may desire to study; but such was not the case at the time of the conversation above referred to.

I had already some knowledge of the working of the Canton Institute, based in part on personal investigation, and in part on conversations with the Reverend J. Wynne Jones, whose energy has founded the Institute and whose earnestness has kept it going. His experience was that but a small percentage of those for whose enjoyment the reading room of the Canton Institute was maintained, made any use of it. When I stated this to Mr. Garrett, he said that to some extent the same thing had been found in connection with the reading room at Mount Clare Works; many local employes of the Baltimore and Ohio Railroad used and enjoyed it, but many never came near it. Reading rooms therefore doing obviously but a part of the work, the problem still remained,—how to make intellectual recreation after working hours accessible and attractive to those who were often too weary to read magazines or enjoy a game of chess or checkers?

As the conversation proceeded, reference was made to the courses of evening lectures organized in England for citizens whose occupation was such as to preclude any great amount of thought as to Art, Literature, or Science. In London and Manchester such lectures had proved very successful; and Mr. Garrett said that if such evening lectures could be organized in Baltimore, he would earnestly do what he could to promote their success. I asked for a few days' time to consult my colleagues in the Biological Department of the Johns Hopkins University, in order to find if they were willing to co-operate with me in delivering a series of popular scientific lectures. They all willingly assented.

The lecturers having been secured, Mr. Garrett undertook to provide the lecture hall, and to pay for the necessary lantern slides, diagrams, and assistants. This pamphlet, containing the text of the lectures and illustrated with lithographs of the figures and experiments displayed, has been prepared at his request and printed at his expense, in order that the lectures given in Baltimore may not only be available in print to those who heard them, but may reach employes of the Baltimore and Ohio Railroad at locations far from Baltimore City.

Before concluding, I take this opportunity to express, on behalf of my colleagues and myself, our appreciation of the attention which our unexpectedly large audiences gave us. Anticipating but two or three hundred hearers, we were confronted with six hundred; and we fear that now and then the diagrams exhibited were not of such size as to be distinctly visible to those at the far end of the lecture room. Our hearers were, however, kind enough to condone such occasional failings, and to send us home grateful to them and pleased with ourselves. No one of us desires to ever lecture to a more friendly audience, or one more generous in its sympathy.

H. NEWELL MARTIN.

I.

HOW SKULLS AND BACKBONES ARE BUILT.

HOW SKULLS AND BACKBONES ARE BUILT.*

By H. Newell Martin, M. D., D. Sc., M. A.

Professor in the Johns Hopkins University.

It has sometimes been my good fortune to visit a machine-shop, and with the friendly aid of those there at work, to learn something about the actions of the machines and the uses of their different parts. As the little knowledge which I have been able to pick up on such occasions has often given me a great deal of pleasure, I have thought that I might perhaps be able, in turn, to interest and entertain you for an hour or so with an account of the structure and uses of some parts of the machines whose examination is my business in life. Just as there are many little things about the making of a steam engine whose object and meaning only those thoroughly trained to such work can appreciate, so with that branch of science called biology which studies living objects: its followers pry into a great many questions and collect a great many bits of out-of-the-way information, whose interest or importance are not readily made clear to those who are not biologists. But, on the other hand, there are both in the structure and working of a locomotive, and in the structure and working of a living animal, a great many things which any intelligent man or woman can understand and appreciate without being either a practical engineer or a working biologist. More especially is this true of the applications of common mechanical principles to secure strength, flexibility, support, and protection to the various parts of a complicated structure.

Of the many examples of the employment of every-day mechanics which we find in the bodies of animals, I have selected as the topic of this evening's talk, some account of the manner in which the skeleton is built; and then a little inquiry to see if we can find out any reasons for its being constructed in the way it is. Of all skeletons that which interests us most is, naturally, the one which each of us has to use every day of his life. So I shall chiefly speak of the human skeleton; but to get a clear idea about it we must begin a little further back, and think for a few minutes about skeletons in general.

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* In the body of the lecture I have acknowledged my indebtedness to Sir Charles Bell; but I desire here also to state that for many of the ideas put forth in it, and for many of the illustrations which I have employed, I have drawn very freely upon his essay on Animal Mechanics.—H. N. M.

We all know what a skeleton is: the hard portion found in the bodies of most animals, serving to support the softer parts and preserve the shape of its owner, and also to enclose and protect certain specially important but delicate organs. Most animals may, indeed, be very well compared to an ordinary railroad train, with its passengers, cars, and locomotive. The skeleton answers to the cars which carry and protect the passengers; the passengers are such things as eyes, and ears, and nose, and brain, and stomach, which are to be carried around in pursuit of information, or of more material gains (as a dinner), or, even, of mere pleasure. The muscles, of which Dr. Sewall will speak to you next week, move the skeleton about, and the skeleton carries the passengers; and so the muscles answer very well to the locomotive of a train.

Now a good railroad car must fulfil two main conditions; it must be capable of being moved without too great an expenditure of work, and it must provide comfort and safety for its passengers in all the ordinary and some of the extraordinary circumstances of travel. A good skeleton has to do exactly the same things; but with one important difference. In a railway train the security of one passenger is a matter of just as much solicitude to the company as that of any other, at least theoretically. Some of us who are not railroad men feel safer if we know there is a director on board. But in the animal body that is not so: some of its passengers are more easily injured than others, and some are of far greater necessity to the creature than others; and these especially tender and especially important parts have, what we may call special cars built for them, in which they can hardly be injured by any such accident as the body is at all likely to meet with in its daily life.

We have all seen examples of two very different kinds of skeletons: those which have no soft skin outside them, and those which have. The anatomists call these two kinds the "outside skeleton" and the "inside skeleton." In Fig. 1* we see a familiar creature with an outside skeleton, and we Baltimoreans, at least, know that the crab has no other. From time to time he grows too big for it, and it tears or splits down the middle of the back. The crab then creeps out and hides away in some hole until he has grown a new suit of armor. In the intermediate helpless condition he is caught and brought to market as a "soft-shelled crab"; and when the soft crab fulfils his natural destiny and comes to table, we all know there are no bones inside to impede our mastication.

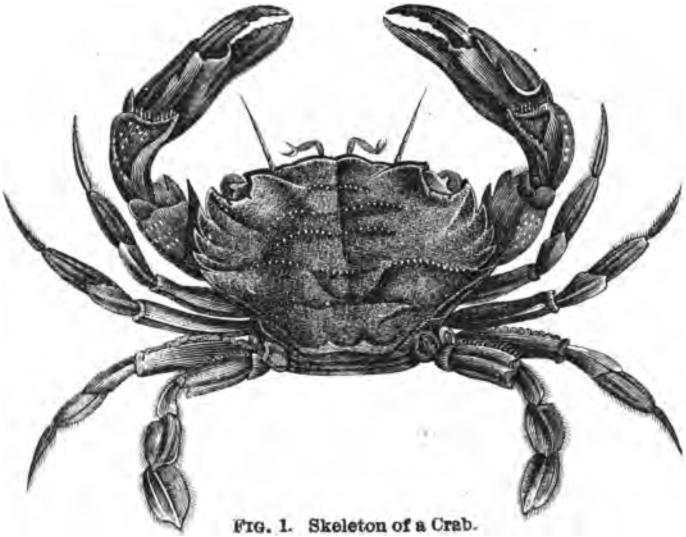

FIG. 1. Skeleton of a Crab.

Most of the higher animals have an inside skeleton; it is less bulky and cumbersome than an outer case and therefore has certain advantages, but it affords less protection: the latter defect is partly compensated for, however, by the fact that chambers or cavities are hollowed out in portions of this inside skeleton, in which chambers very delicate organs are hidden away; so that though it lies inside the skin and muscles, it really is an outside skeleton to many parts whose injury would be especially dangerous.

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* The various skeletons, &c., represented in the figures were, in the course of the lecture, shown on the screen by a stereopticon.

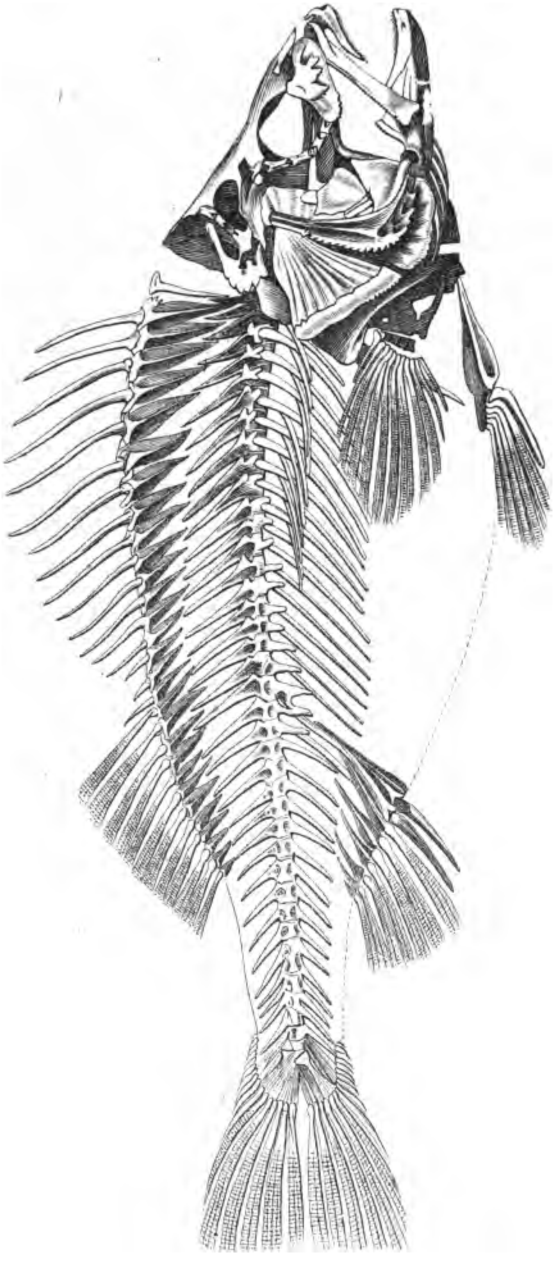

FIG. 2. Skeleton of a Perch.

The foundation of this internal skeleton is in most cases a *backbone,* which usually bears a skull on one end of it; and in order that we may all have some clear idea as to what we are talking about, which is the first condition of all talking that is worth the doing, I will first show on the screen a number of skeletons of backboned animals.

First then we have the skeleton of a perch (Fig. 2), in which you see the nearly straight backbone running along the body of the animal, and made up of a number of separate pieces, put together end to end. It bears the back and belly fins above and below, the tail fin behind, and the large skull in front.

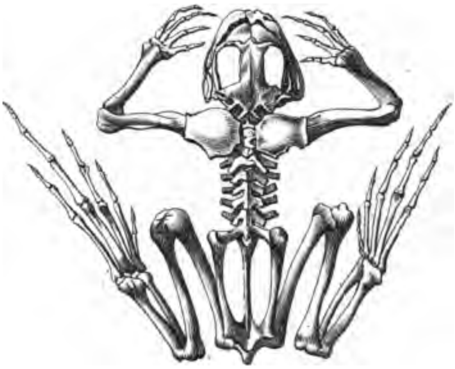

Fig. 3. Skeleton of Frog.

Next (Fig. 3) we have the skeleton of another well-known backboned animal — the common frog. In it we find a short backbone, made up in its front half of a row of separate pieces, and posteriorly of a long undivided slender bone. It supports the limbs and carries the skull; and in this skull I can point out to you, better than in the more complicated one of the fish, that the brain-box is very much smaller than its face part, which is made up mainly of the jaws and the parts which support them. In the frog it is only the small central part, lying between the two great holes, which are the sockets for its big eyes, that has any brain in it. In a fish this is still more the case; it has a huge head, but most of this is face, and very little indeed is brain-case. In every animal with a bony skull we find in fact that the skull consists of two primary parts—brain-case and face-skeleton—and the higher the animal, as you will see when we proceed, the larger is the brain-case part of the skull in proportion to the face part. Some of you may perhaps have already on other grounds arrived at the conclusion that the greatest amount of "cheek" is not always found associated with the largest supply of brains.

The next illustration (Fig. 4) shows a creature well known about these regions, the snapping turtle. It, you see, has both an inside

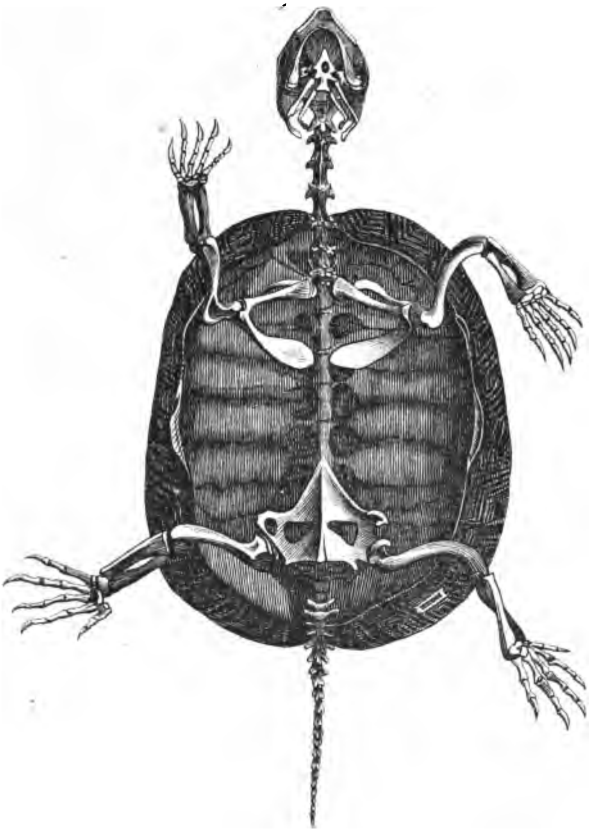

Fig. 4. Skeleton of Turtle.

skeleton and an outside. The inside skeleton is made up of backbone and skull, and of bones supporting the limbs: in addition we find large bony plates which form a case for all the trunk of the animal, surrounding many of its most vital organs. A turtle is thus a good deal like one of the new ironclad men-of-war which

European countries are now spending their treasure on. It is armor-plated about its most important regions, but the less essential are left without armor, so as to gain in mobility and lightness. The brain is protected by the skull, so needs no additional outside skeleton, and moreover both it and the limbs can be drawn back out of the way of danger under the projecting edges of the upper and lower shells which cover in the trunk of the snapper, and in this respect the turtle is much better off than the ironclad. The turtle, however, carries so much armor as to be impeded by its weight, like a mediæval knight in his coat of mail. He cannot move about as actively as the fish or frog, and so misses a great many opportunities of pleasure or profit which a more nimble creature could take advantage of. The snapper in fact suffers from "over-protection," a phrase with which some political economists have recently been making us pretty well acquainted in connection with the "infant industries" of these United States.

Next (Fig. 5) we see the skeleton of the most backboned creature in the world, a big snake. Here we find again a skull in front, with big jaws; and, what we did not see in the frog, a great many pairs of ribs carried by the backbone.

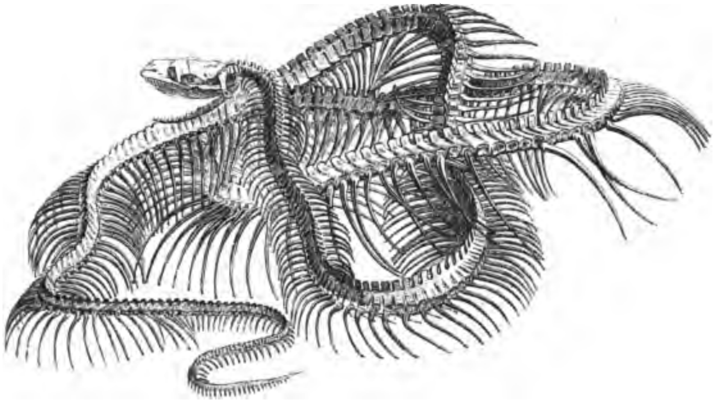

Fig. 5. Skeleton of Python snake.

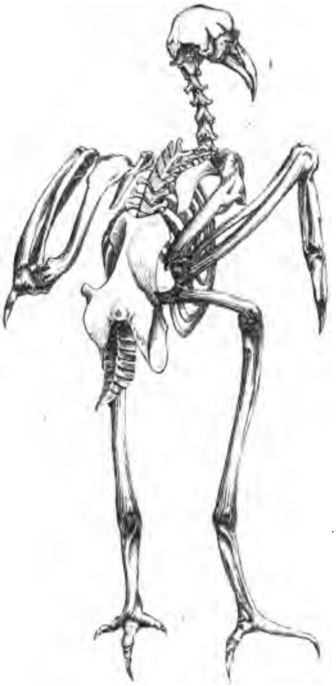

Fig. 6. Skeleton of Eagle.

Now we come to a bird, the American eagle (Fig. 6); who never knowingly turned his back on foe or friend, though he has, involuntarily, been rude to the artist. In the eagle we again find a backbone forming the central support of the whole body, and bearing the skull and limbs. And we see the same thing in the next illustration, which shows the skeleton of an ox (Fig. 7).

Ascending in the scale of backboned animals, we come next to the ape (Fig. 8), and finally to man himself (Fig. 9), with his backbone bearing, as in the other cases, a skull on one end and limbs on the sides.

So long as we look at the skull and spine by themselves,

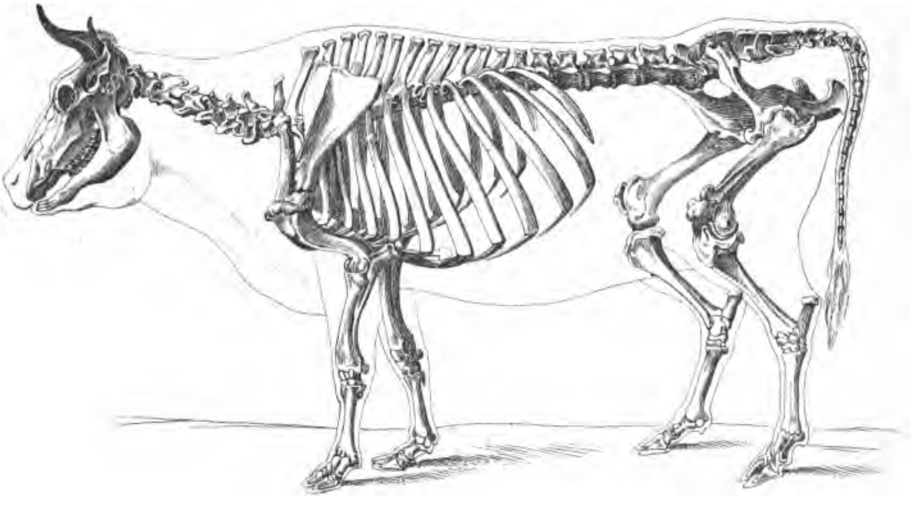

Fig. 7. Skeleton of Ox.

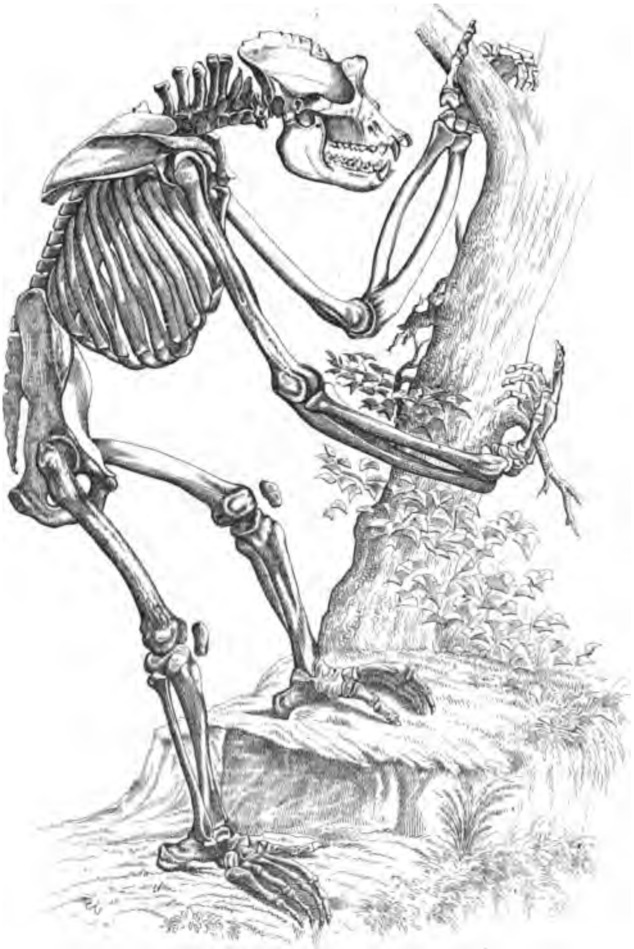

FIG. 8. Skeleton of an Ape.

the main thing which strikes us is their function as supporting frameworks; but if we now turn to consider them in connection with the softer parts of the body, we find they are also protective cases; they conceal, in more or less completely closed boxes, some very important organs. The eye lies in a bony socket, only open in front; the smelling part of the nose lies in a bony vault near the forehead and covered over by the "bridge" of the nose; and the essential

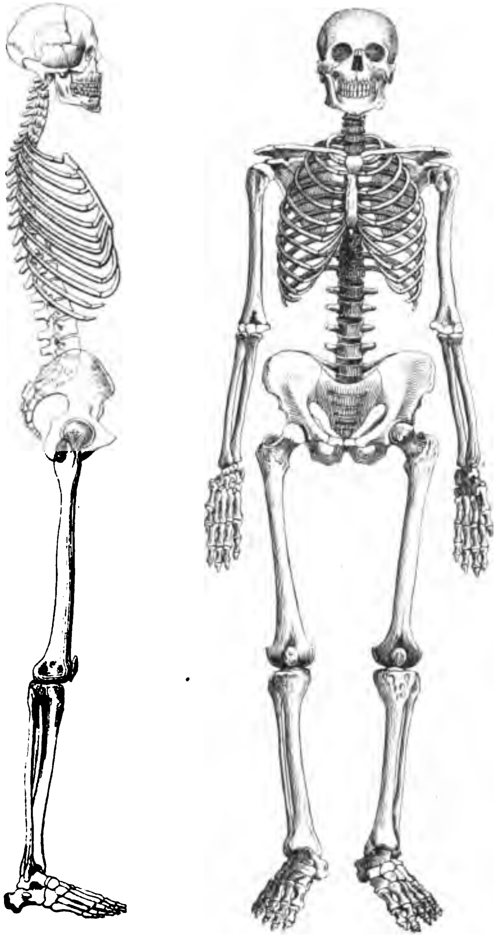

FIG. 9. The human skeleton.

part of the ear lies buried away inside one of the hardest and thickest bones of the head, the part of the ear which we see projecting from the side of the head being really of comparatively little use. Through eyes, nose, and ears we all get information of vast importance to us; and the organs concerned being of very tender structure, are accordingly specially guarded from injury. But there are even more important parts than any of them. Without the brain, and the spinal marrow (which forms a pathway from the brain to most parts of the body), eyes, ears, and nose would be useless; and these fundamentally important parts, brain and spinal marrow, lie far away from the surface in bony chambers built with every precaution for their safety: the brain in the skull, and the spinal marrow in the backbone. Just where these parts lie in our own bodies we learn from the next illustration (Fig. 10), which represents what would be seen if a man's body were divided accurately along the middle line into right and left halves, and the cut surface of the right half examined. The bones exposed are printed in black. Above we see the skull with its face parts comparatively small, and its brain-case part, containing the brain N^1, quite large. From the brain we see the spinal cord, N, running along the hollow of a tube formed by the backbone.

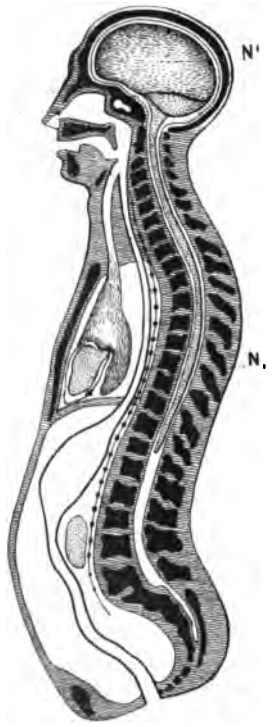

Fig. 10. Diagram of a section along the middle line of the body.

Now what it is that happens when we wish to move an arm or a leg, or when we feel a touch on hand or foot, is a very complicated matter. But whatever it is, it depends on the integrity of the spinal cord; and apart from all theory, certain broad facts are certain. When I *will* to walk, the first stage in the process, the willing, occurs in the brain: from the brain some result of my *willing* travels along the spinal marrow, and from the spinal marrow, by certain fine white cords, called nerves, to the muscles which move my legs. On the other hand, if some one is so rude, or so unfortunate, as to tread upon my toes, the pressure on the toe starts something which travels along a nerve to the spinal cord, and along the spinal cord to the brain, and it is only when it reaches the brain that I know anything about it. The spinal cord is therefore an essential link between our consciousness either of willing or feeling, and the trunk of the body or the limbs. Persons whose spinal marrows are diseased for a little distance in the upper part of the chest region often live a long while; but no effort of their will enables them to move any part of the body below the level of the diseased portion of the spinal marrow, nor does any cutting or pinching or burning of parts of the body below that level cause any feeling. The spinal cord, therefore, as being a necessary connecting link between consciousness and most of the body, is an organ of primary importance; it is, to use our former illustration, one of the passengers in the railway train of the body whose safety must be especially looked after.

If we come to consider how such safety might best be secured, the first answer would probably be, put the spinal marrow in a strong bony tube, buried away from the surface, and perforated at intervals with small holes to allow nerves to run in and out between it and other parts. But a rigid rod passing along a man's back and neck would very seriously interfere with freedom of movement. When we see a person with a stiff and awkward clumsy gait we say "he walks as if had swallowed a poker"; and a long unbending bone run down the middle of the body to protect the spinal cord would be in fact a very inconvenient poker. In order to execute agile movements and maintain our balance, the main axis of the body must be flexible. On the other hand, if the protecting tube in which the spinal marrow lies bent sharply, it would crush its contents. So we are met by the mechanical problem, how to provide a protecting tube which shall contain the spinal cord and be stiff enough to support the body, and at the same time be flexible, and yet not able to bend so sharply as to nip the spinal cord lying inside it.

Utilizing the hint given to us in the fact that backbones are made up of a number of separate pieces, we can make something that fairly well answers such requirements. I have here what was yesterday a broom-handle; as you see, it has been sawed across into a number of separate pieces, each about an inch thick, between each piece a pad of rubber has been placed, and the whole has been strung tightly on a wire to keep its parts together. Instead of the unbending broom-handle we have now got a rod which is quite flexible; it can be bent to a considerable extent in every direction, and yet it makes no sharp bend at any one point. If it were hollow, and I ran a piece of rope down its middle, the rope would bend with the flexible rod, but would never be nipped and crushed at a sharp turn.

It is in exactly this way that our backbones are built; each is made up of a number of separate pieces, having a ring at its back. The whole row of rings makes up a tube in which the spinal marrow lies, and between the rings nerves run out to various parts of the body. Each separate piece of the backbone is called a *vertebra;* and the spinal column is thus made up of a number of vertebræ piled one on another. Two vertebræ from the middle of the back are shown in Fig. 11.

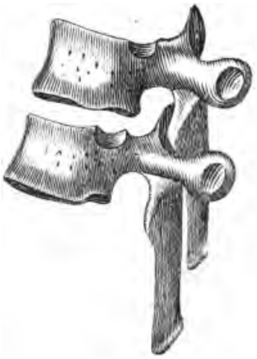

Fig. 11.

You see that the two bones do not meet in front; that is because a soft elastic pad originally lay between them, as the pads of rubber between the bits of my broom-handle, and when this is dissected away a space is left between the bones. Behind, bony bars from one bone touch those of the other, but at those points there are joints so that one can glide a little bit over the other.

Our next illustration (Fig. 12) shows a section made along the middle line of a fresh spinal column, and there you see the soft pads between each of the vertebræ.

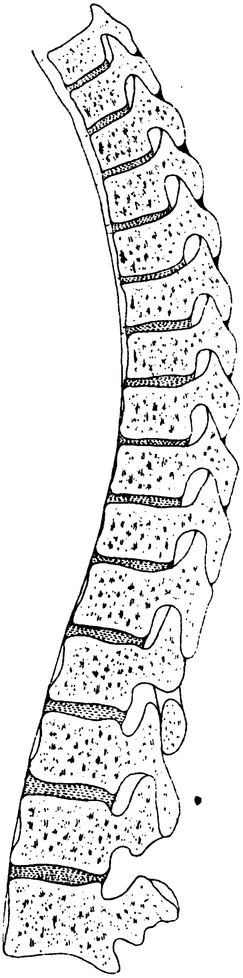

Fig. 12. A section along the middle of part of the spinal column.

We thus find how the backbone is built so as to be firm and support the body; so as to surround and protect the spinal marrow; so as to be flexible in all directions, and yet never to make such a sudden bend as to crush the spinal cord inside it. It is, I think you will agree, a very beautiful piece of mechanism.

Having seen how the spinal marrow is cared for, we now pass on to consider the arrangements made to protect the brain.

The brain-case is essentially a dome, with tolerably thin roof and sides, and a thicker floor. Now, in architecture a dome of masonry is a particularly hard thing to build. The weight of its upper part tends to make its sides bulge out and give way; and to prevent this the tiers of stone in it have to be very firmly cemented together. In some domes, as that of St. Paul's Cathedral in London, strong iron chains are run all around at different levels, imbedded in the masonry; they serve to keep the sides from being pushed out by the weight above. Again, where the bottom of a dome rests on the walls which bear it there is a great tendency for these to be pushed apart, by the weight of the dome acting downwards and outwards along its sloping sides; and architects have to take very special precautions so to construct and support the walls which carry the dome that they may be able to resist this "lateral thrust," as it is called.

Now, our skulls are domes, and yet we know we can carry quite a heavy weight on the head, or bear a severe blow on the crown without having the bones crushed in. Only to-day I saw in the New York *Herald* a short paragraph containing an account (which may or may not be true) of a woman who fell sixty feet down a well and bumped her head on the bottom, and yet was none the worse for it; whether by knowledge or accident, the reporter got the matter right, for he wound up by saying she was not injured "because she fell on her head." The skull is, in fact, almost the strongest part of the skeleton; if a mule kicks a man on the arm, or leg, or on his ribs, the usual result is a considerable breakage; but we all hear now and then of colored brethren who have risen up smiling after a kick on the skull.

Now let us see how this bony dome is built so as to have such strength. Conceivably it might be made of one rounded bone, all in one piece; and so there could be no pushing apart of one bone from another when a blow fell on the top of the head. But in that case our brains would be pretty much like a crab's body, shut up in a case which could not grow wider, and which would have to be shed from time to time, as our brains grew during early life, leaving them in a "soft-shelled" state until a larger skull could be again formed around them. In Fig. 13 you see that in fact the skull is made up of a number of separate bones, closely united. These bones grow at their edges during childhood, and so make the brain-case bigger as the brain increases in size. In children there are many more separate pieces in the skull than in a full-grown adult; and in advanced old age some bones

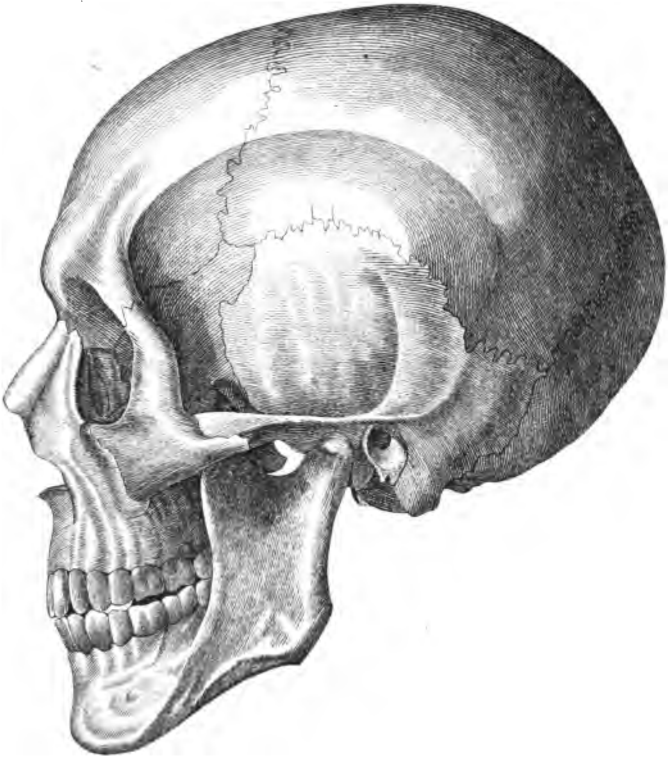

FIG. 13. The bones of the human skull

which you see in the figure as distinct grow together into one piece. During most of life, however, the skull dome is made up of many distinct bones: how are they fixed together so that a weight on the top of the head will not push them apart? As you see in the figure it is by a minute and beautiful dovetailing, which locks together their margins, so that the bones cannot be forced asunder without breaking off their interlocked edges.

Next, how is the thrusting outwards of the bottom of the dome prevented? Partly of course by the firm union of the bones above; but partly also by a sort of buttress on each side. In Fig. 14 we see that the bottom edge of the dome rests on a stout bony base; and that from this foundation a plate of bone reaches up on each side and overlaps the lower ends of the bones which form the sides and roof of the skull: thus they are prevented from being pushed outwards. Nor is this all. Suppose a carpenter has to build a vaulted roof: we know that the weight of the roof pushing down and outwards on the walls would tend to thrust them apart. This he prevents (Fig. 15) by putting in a "tie-beam," running from rafter to rafter across the roof, and holding their lower ends together. In the skull we see this same thing. In figure 14 we see a tie-beam joining each side of the bottom of the skull roof; and in the living state this tie-beam is very firmly fastened to the bones on each side of it by stout cables called ligaments. By the dovetailing of its bones, by the buttresses on its sides, and by the tie-beams at its base, the brain-case is thus made able to bear heavy blows or carry heavy weights without flattening down and crushing the brain.

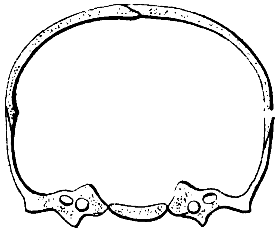

Fig. 14. A section across the skull.

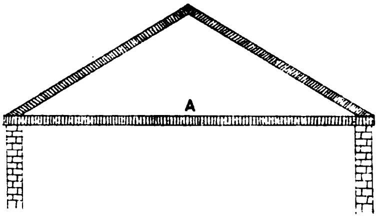

Fig. 15.

In the structure of the separate bones we find still other arrangements to guard the brain from injury, as was pointed out by Sir

Charles Bell, to whom I am indebted for many of the ideas which I have the honor to lay before you this evening. Apart from any flattening in of the whole skull, the brain may be injured by an instrument piercing or crushing a single bone. To resist a sharp instrument we need something very dense and hard, and calculated to make a point glance off without penetrating. This is found in the inner layer of each bone on the roof and side of the skull, which is so hard that a steel point will not readily pierce it. In fact its texture is so like that of glass that anatomists call it the glassy layer.

So far, so good. But this glassy layer, like glass itself, is brittle and vibratile. A blow on it would probably shiver it into fragments, and even if it did not crush it, would set it ringing and vibrating.

If I strike this glass bell with my knuckle you hear it sounding for some time all over the room; and we know that when anything gives off sound it is because it is vibrating or shaking very rapidly. If our brains were in such a glassy case, a tap, not powerful enough to break the case, might nevertheless set the skull vibrating and jar the brain. How can this be prevented?

When I take this damp cloth and wrap it around my bell, and now again strike the glass with my knuckle, you hear for each knock a dull muffled sound which ceases at once. There is no continued ringing as when the bell was uncovered. We see then that if we cover, by a soft damp substance, a thing which tends to keep on vibrating in consequence of a blow, we can nearly completely prevent its vibration.

This is just what we find in our skull bones. Outside the glassy layer is a soft, damp layer, and so a blow on the head cannot set the bones all vibrating and jar our brains.

But the damp cloth over it will not protect my glass bell from being shivered to fragments if I strike it with a heavy hammer. To protect it from such a blow I must encase it again in a tough, stout covering, strong enough to bear the blow of the hammer, and yet not brittle or it would be broken into fragments by the stroke.

This case is represented by the outermost layer of our skull bones, which is tough, and fibrous, and strong, pretty much like a good bit of oak in its properties. It bears a pretty severe blow without being broken, and the force of the blow is further weakened by the soft middle layer under it, and so does not reach the brittle inner table with sufficient force to splinter it. If you turned an ordinary china cup upside down, covered it with raw cotton, and then fitted a case of good tough wood over the raw cotton, you would have a pretty good model illustrating how the skull bones are constructed. Anything placed under the cup would then be protected by the tough outer layer from injury by heavy blows with a blunt instrument; by its hard inner china layer from penetration by a sharp instrument which might pierce the outer and middle layers; and from jarring by the soft packing around the cup which would check its vibration: this packing also serves to greatly weaken the force of heavy blows on the outside which might otherwise break the brittle china. Our brains are protected just in the same way as the object under the cup would be.

Of course with sufficient violence we can break through the skull as we could the cup and its coverings, but nature only looks out for the average chances, and does not provide against extraordinary contingencies. None of us could carry around a skull strong enough to resist crushing by a locomotive, or penetration by a bullet; and, anyhow, railroad accidents and rifles were unknown when man was invented.

Now, if you are not tired out, I would like to point out to you some arrangements in other parts of the skeleton which are also calculated to ensure the safety of this very important passenger, the brain. The brain, as a passenger, is an object which has to be carried about from place to place; and you all know that man carries his brain in a different position from that in which four-footed animals carry theirs. He walks on one pair of limbs instead of on all-fours, and carries his skull above instead of in front. No creature, not even an ape, walks as erect as man. Fig. 16 shows the usual position of some of the most manlike apes, compared with that of man himself when walking. An ape can keep up pretty straight for a short time, but if you watch him you see that is not his natural mode of progression. He leans forward, and helps himself now and then by resting the hands, at the ends of his very long arms, on the ground.

Now if you saw a locomotive made like a bicycle, to run on two wheels instead of four or six, you would expect to find peculiarities

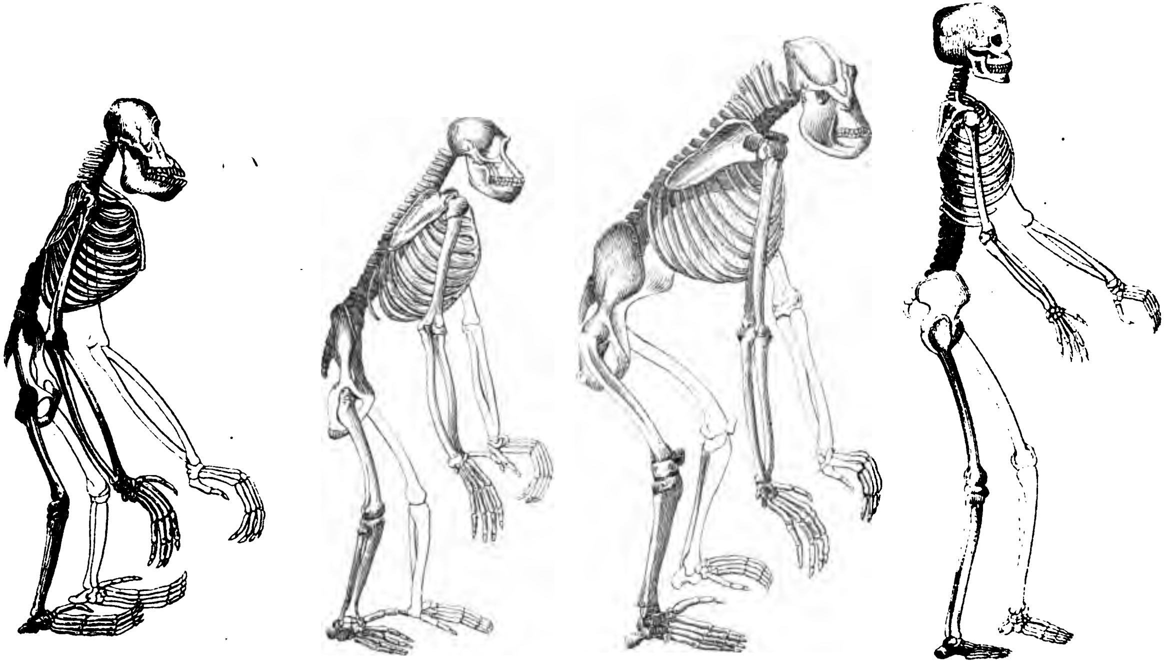

FIG. 16. Showing the natural standing position of man and some of the higher apes.

in its structure; and when we find most animals going on four legs and man on two, we naturally expect to find something in the structure of the human body which should be peculiar to it, and related to this peculiar kind of locomotion. On comparison we do find a good many such, but on the whole, perhaps, less than we might have expected. The general plan of the body in a man, and an ape, and a horse, and a dog, is very much the same; only details are varied.

One of these details is shown in Fig. 17, which represents the skull of a man and of a gorilla, both seen from the under side. You notice that in man the bony knobs *a* which fit on to the top of the backbone, and form the bearings of the skull, are nearly in the middle of its under surface. In the ape the face part is so big compared with the brain-case part, that the skull does not balance on the top of the backbone as our skulls very nearly do; not quite, though, for those of us who have been sinful enough to go to sleep during a long sermon or a dull lecture know the sudden nod that wakes us when, in our sleep, the muscles holding the head erect let go their hold, and the extra weight of the front part of the skull jerks the chin down towards the chest. Our skulls, however, so nearly balance on the top of the backbone that we need but little effort to keep them erect in the position which is necessary for conveniently seeing in front of us when we walk. On the other hand

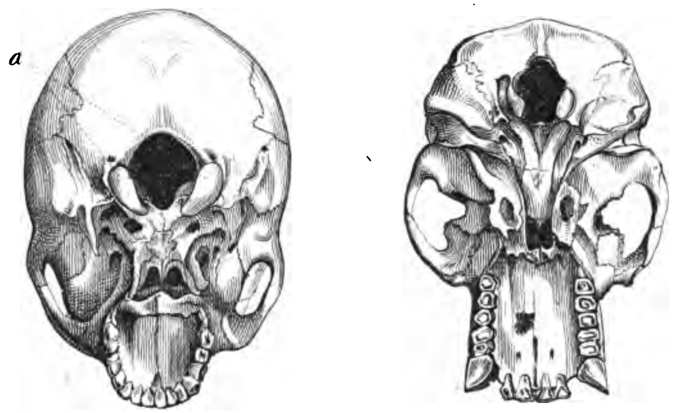

FIG. 17. The under side of the skull of a man and of a gorilla.

an ape's badly balanced skull makes it quite a labor for him to hold his head up and look things "full in the face," like a man.

The fact that our skulls are carried on the end of an erect spinal column exposes them more to jarring when we walk. Every time the foot reaches the ground a certain jar or jerk is sent up the bones of the legs and along the backbone to the skull. When an animal goes on all-fours this is much less the case. The jolt acts vertically, and the spinal column is horizontal, and has the skull away at the end of a neck in front. The jerk acts across the length of the spinal column instead of along it, and so but little of it is transmitted to the skull.

In connection with this difference of natural standing posture we find certain peculiarities of the human spinal column, calculated to make it more springy and less liable to send jars and jolts up to the skull from the feet. If I take this straight elastic rod, put one end on the table and strike the top end with a hammer, you all readily understand that the blow of the hammer is transmitted with nearly its full violence and suddenness to the table. But if now I take this rod, quite like the other except that it is bent, and treat it similarly, you see that when I strike its upper end it bends somewhat. The table, instead of a sudden violent blow, now gets only the more gradual springy push of the bending elastic rod. Now if you look back at the figures of backbones which we have seen to-night you will see that man's is distinguished by its curvatures (see side view, Fig. 9). It is not curved once only, but forwards in the neck, back in the chest, and forwards again in the loins. In walking it acts like the bent rod. The sudden jars which might otherwise jolt our brains are turned at each step into more gentle, gradual pushes by the bending springiness of the curved backbone.

Still further, we find in the construction of the human foot another arrangement to protect our brains from that extra risk of sudden jolts which results from our mode of walking.

You all know how a carriage-spring is built: Two curved elastic bars of steel are fastened together at their ends, with their convex sides outwards. The axle of the wheel is fixed to the middle of the under side of the lower rod, and the weight of the carriage bears on the middle of the upper side of the upper bar. When the carriage wheel jolts over a stone, the shock transmitted to the carriage only acts through the spring: each curved rod straightens a little, and then gradually resumes its original shape. So the occupant of the carriage, instead of experiencing a sudden jerk, feels only a gentle swaying up and down. The arched springs turn the sudden movement into a gradual one.

The bones of our feet are so arranged as to make a springy arch, which answers to the upper half of a carriage-spring. Here you see them (Fig. 18). When we walk our weight bears down on the crown of the arch at *Ta*, where the leg bone joins the foot. This part of the arch does not touch the ground, but only the end of the heel bone, *Ca*, behind, and bones *M* at the roots of the toes in front. The arch between these two bearing points is made up of a number of small bones, each of which can glide a little over its neighbor, and the whole is springy and elastic. Hence when a foot is placed violently on the ground, the arch yields a little and flattens out under the sudden pressure, and then gradually curves up again, and thus violent jerks, which might jar the whole skeleton up to the skull, (as we know in fact they do if we have the misfortune to jump and come down on hard ground on our heels) are turned, by the elasticity of the arched instep, from sudden shocks into more gentle gradual movements before they are transmitted to the rest of the body.

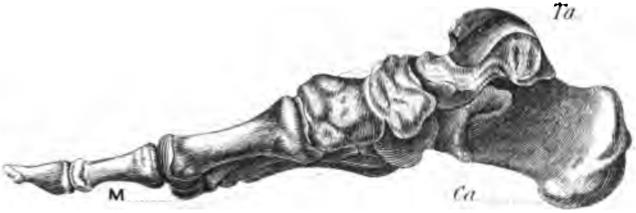

Fig. 18. Skeleton of the human foot.

And now, ladies and gentlemen, time is up, and it is my duty to get to the end of this lecture as soon as possible. I have always noticed that when a train is behind time the conductor accepts the fact with equanimity, though there is apt to be growling among the passengers. If I were of a vindictive disposition I might try get some little revenge for sundry "unavoidable detentions"—that is the correct phrase, is it not?—by keeping you here a little longer; and if you belonged to the Pennsylvania Road, I believe I would try it. As a punishment for my sins I have had very often this winter to travel from New York to Baltimore by that line, and hardly once did I get back near enough schedule time not to find my supper spoiled. But we all know the Baltimore and Ohio never behaves that way; so it only remains for me to thank you for the courteous manner in which you have received me to-night as your conductor over a short side-branch of science; and to express the hope that nothing which I have said concerning the skill and care with which nature has protected our brains and spinal cords will lead any of you to make an experimental investigation of the matter on a large scale. Nature has done very well, but she has unfortunately not afforded all the strength requisite to bear us in safety through a railroad collision.

II

HOW WE MOVE.

HOW WE MOVE.

By HENRY SEWALL, B. SC., PH. D.

Associate in Biology, Johns Hopkins University.

We all know how to move; perhaps some of you will desire to put that simple feat into practice before I get through.

We know that all parts of our bodies may be moved, but we are also conscious that not every part is capable of moving itself. Thus the hair and the nails never move alone, and when the eyes roll about you feel sure that the eyeballs are moved by something outside of and behind themselves. In fact, all this bodily motion of which you are conscious is carried out by one definite part of the animal apparatus—the muscles. The muscle of an animal is that more or less red flesh which we commonly eat in beefsteak and mutton-chop. It is the "lean" of the meat. If you look carefully at it, you will see that the muscle has a grain, not unlike that of a deal board; and if you pick the muscle to pieces along its grain, you can separate it finally into an immense number of very delicate threads, which can be no farther divided. These are the ultimate muscle fibres, each of which is finer than the finest thread of silk (Fig. 1). Such a single fibre never exists in the body, but muscles as we see them are made up of an immense number of such tiny threads tightly bound together side by side (Fig. 2). So much for the living muscle when it is at rest. So far as I have described it the muscle may seem to be nothing but a peculiar kind of animal string or cord. But there is a vast difference. You know that a string may be cut, or burnt, or shocked with electricity, and it will not move in the slightest. But let us do any of these things to a living muscle, and a most wonderful change takes place in it. Suppose I pass a shock of electricity through one end of a muscle fibre: immediately the fibre becomes swelled and thickened at that end, and the thickening runs along the whole length of the fibre faster than the eye can follow, until the whole

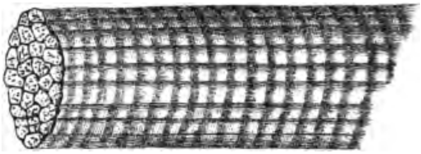

FIG. 2. A bundle of muscle fibres, magnified.

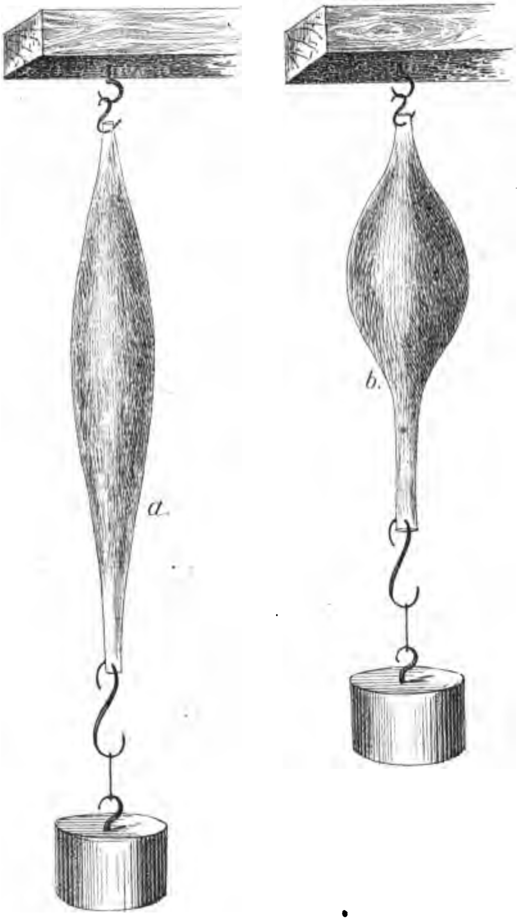

FIG. 3. *a*, muscle at rest; *b*, muscle contracted.

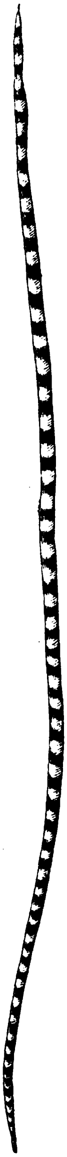

FIG. 1. A single muscle fibre, magnified.

fibre becomes thicker than before, as a rope does when wet with water. Compare the length, now, of this excited and thickened muscle with that of the resting and thinner one; you will see that what the muscle has gained in thickness it has lost in length (Fig. 3). Therefore, whenever a living muscle is excited it shortens or contracts, and muscular contraction is the direct cause of all the visible movements of the body.

Now if this were all, muscles could be of little use to us. If our bodies were made up simply of a soft mass of muscles we should not be able to do much with them. A person so constructed might prove a great attraction, as the india-rubber man at the Dime Museum, but he could not be of much use in a machine shop.

You know that when a heavy weight is to be lifted, you must rest your lever or crowbar on a firm fulcrum or pivot, upon and about which you turn it. Now, in the body, the muscles work upon hard unyielding levers in the same way; the long bones of the skeleton are the levers, and the joints mark the places of the fulcra. It is by pulling on these long bones and moving them round their joints that the muscles move the body. You see thrown upon the screen the shadow of the living hind leg and foot of a frog (Fig. 4). *a* is the calf muscle, which is fastened at one

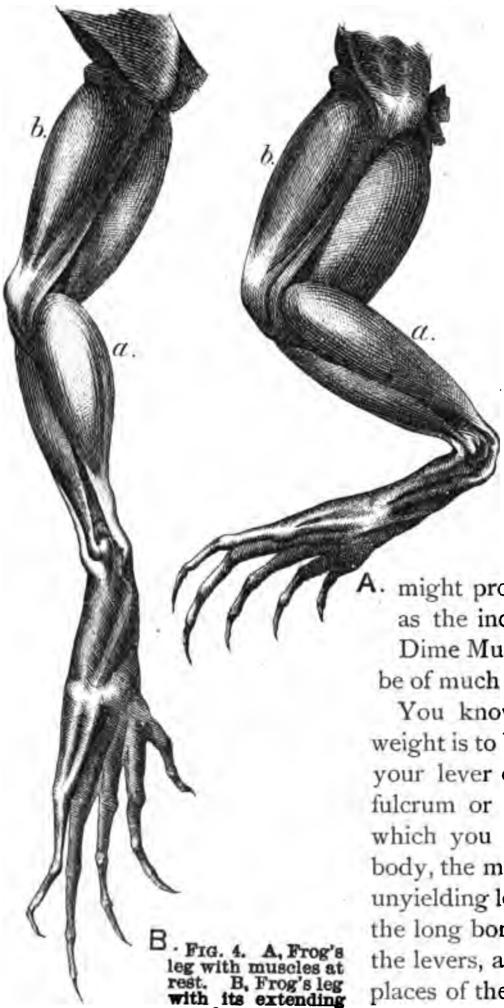

Fig. 4. A, Frog's leg with muscles at rest. B, Frog's leg with its extending muscles contracted.

end to the knee, and at the other to the heel, as it projects back of the ankle joint. When the muscle contracts the heel is pulled up and the rest of the foot is thrown down, turning round the ankle joint as a pivot. This is one of the chief muscles which the frog uses when it leaps. *b* is one of the muscles whose contraction straightens the knee. Do not despise this experiment because it is performed on a frog, for each of us depresses his foot and raises his body in the same way. When you stand on your toes you can notice that the calf muscles become harder and thicker; they are powerful enough to lift the whole body when they contract. All the kinds of levers we know are represented in the body. In the case just described the power was applied at one end of the foot lever, outside of the fulcrum and the weight. But when the forearm is raised, the swelling and hardening which you notice on the upper surface of the arm is caused by the contraction of a large muscle which is firmly fixed to the shoulder above, but below pulls upon the bone of the forearm at a spot *between* the fulcrum at the elbow joint and the chief weight to be lifted. The manner in which the muscle raises the forearm is illustrated in Fig. 5.

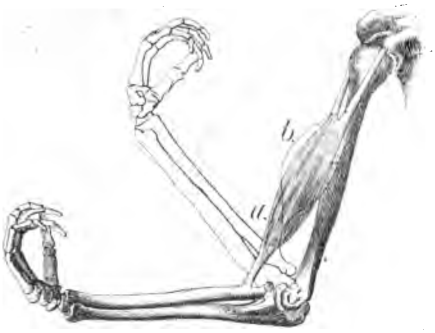

FIG. 5. Movement of the fore-arm: *a*, the muscle at rest; *b*, the muscle contracted.

No doubt you are disappointed that the whole matter appears so little complicated. It seems ridiculously simple that all the delicate movements in which some of you have been training for years, are brought about merely by the pulling together of the ends of muscle fibres. But it is the grand simplicity of nature. For without this contraction of muscle, not one work of man that exists could have been produced. No thought could have found expression, no mighty engines or delicate machines would bear witness to the splendor of the human intellect. If the muscles of our hearts and chests ceased but a few seconds to work, this hall should be converted into a great tomb; we should all have ceased to live.

Here is a little instrument which may have a familiar look to some of you (Fig. 6). It is copied from the ordinary railroad

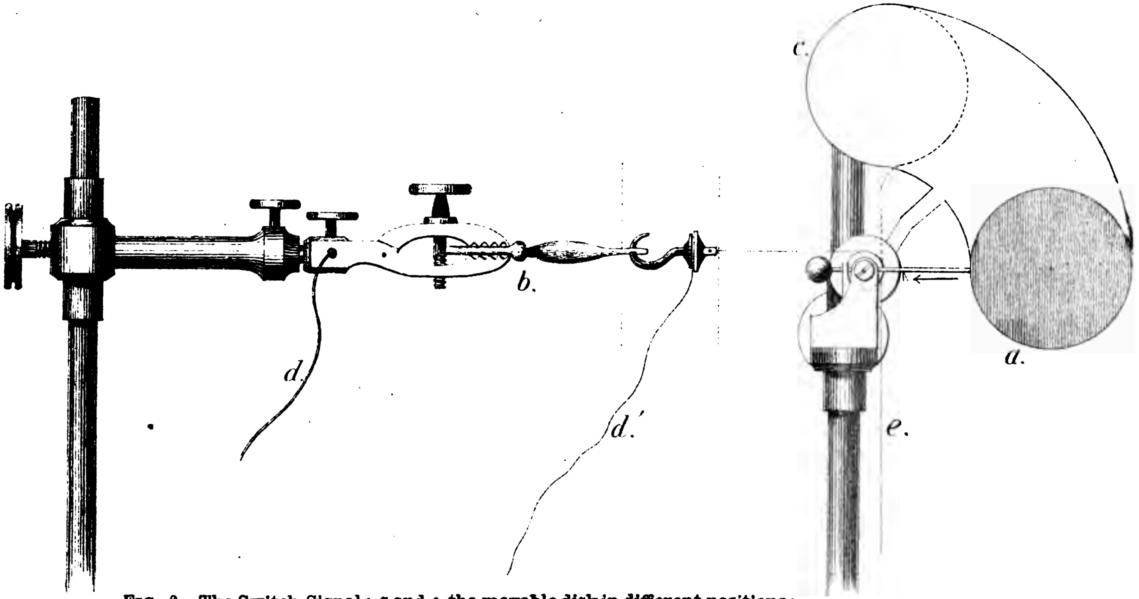

FIG. 6. The Switch-Signal: *a* and *c*, the movable disk in different positions; *b*, the muscle; *d* and *d'*, the electric wires; *e*, the weighted string.

switch signal. The disk *a* is made fast to a movable axis, around which a weighted string is wound. The muscle is clamped and held firmly by one end at *b*, while the string, which passes over the revolving axis, is fastened to its free end. If the muscle contract it pulls upon the taut string which, by its friction, turns the axis over which it falls, and with it the attached disk, so that the latter takes up a new position, *c* (dotted disk *c*). The electric shock is conveyed through the muscle by wires, one of which is made fast to each end. If, then, the muscle contract the disk flies up, and when the shortening is over the disk regains its horizontal position, being pulled down by the weighted string. Notice that every time I send into the muscle a single shock the muscle answers by a single rapid contraction, occupying from first to last not more than $\frac{1}{10}$ second, and there are just as many contractions as there are shocks, and no more. The same is the case with our own muscles; one shock of electricity would cause in them one fleeting spasm only. It is very evident that such a kind of motion should be of little use to us. A person with St. Vitus' dance could hardly become a good machinist. How is it, then, that we are capable of such regular, even, long-continued contractions as is the case? In the same way, probably, as I was able to show you a steady, long-continued contraction of the frog's muscle on the screen, and that is very simple. Suppose when a muscle is at rest it is of the length represented in *a* of Fig. 7. Give it a shock,

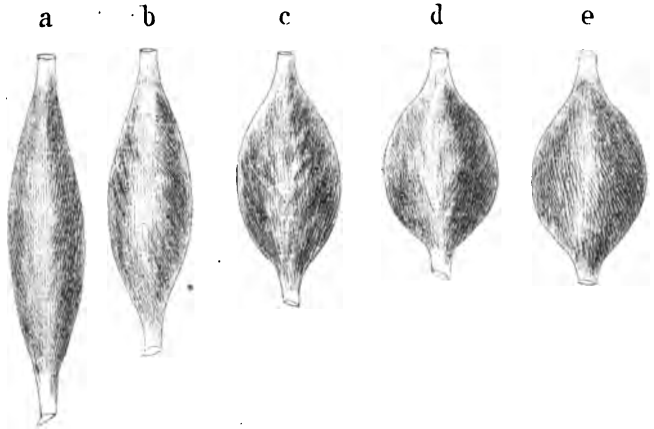

Fig. 7. Showing how fleeting single contractions may be heaped together to form long-continued ones.

and it takes the form *b*; shock it again before it has had time to relax and it contracts still further to the form *c*, and so on until the muscle can shorten no farther; then a continuation of the electric shocks serves simply to keep the muscle in that steady, uniform state of contraction. You notice that I can produce this effect on the railroad signal. When the shocks succeed each other slowly the disk simply moves up and down, but as the succession of excitements becomes gradually more rapid the disk oscillates less and less, moving higher, till finally it reaches the top of its path and stops there, showing that the muscle is in a state of steady contraction.

When one makes a voluntary motion, the will sends along the nerves (of which I will speak to you in a moment) a succession of excitements, of what kind we know not, and these stir up the muscle in the manner described. When the will is weak, or the body diseased, when one suffers from terror or emotion of any kind, when a man visits the dram shop too often and cares more about his bottle than a good constitution, you will notice that that person's movements lose their natural smoothness, and when he lifts his hand it is shaking. That simply means that his will is not able to send to the muscles a regular succession of impulses to excite them. It happens no doubt in a way which we are able to imitate on our railroad signal, Fig. 6. You see that when the shocks succeed each other rapidly at regular intervals, the disk remains steady in the upper part of its path, but so soon as the succession of shocks becomes irregular, the disk begins to shake back and forth like a trembling hand.

You all know what a machine is. Broadly speaking, it is an apparatus to do work. Perhaps you have seen enough to believe that the muscle answers this definition, and is a true machine, for it can lift and carry burdens and do work. The efficiency of an engine is measured by the amount of work that one can get out of it by burning a certain amount of coal. For the best engines that man has made, this ratio is about one-tenth. That is, of all the heat made by burning its coal an engine can turn only $\frac{1}{10}$ into work, the other $\frac{9}{10}$ being lost as heat. But nature's engine, the muscle, is more efficient than this. As nearly as can be calculated, more than $\frac{1}{5}$ of the energy which the muscle expends in contraction goes to doing work.

We have been getting a good deal of work out of this muscle engine, and that energy must have been stored up as fuel in the muscle substance. The change which takes place in it on being excited is a good deal like that which happens on the explosion of a charge of gunpowder. Energy was stored up in the charge, and then all at once set free when the powder was ignited. Notice further this peculiar property of each—that the amount of work gotten out of either powder or muscle is independent of the amount of energy you apply to set free that energy which is stored in either. A small percussion cap can fire off a barrel of gunpowder as easily as could the heat of a volcano. In like manner the electric current we have used to stir up this muscle could not itself accomplish more than a small fraction of the work it causes the muscle to do. But the muscle has more remarkable powers still. It is a store of energy, as the gunpowder is. But you know that if you put a lighted match to a mass of powder the whole of it will explode and be used up at a single discharge, whether it be made up of a single grain or be as large as a mountain. You have seen, however, that from the muscle we can get explosion after explosion of nearly equal strength. Still more than this; not only is not all of the contractile material in the muscle used up at each shortening, but the strength of the different contractions may be varied; in other words, the energy produced in the different explosions can be regulated so that they shall be of any desired feebleness. You see plainly here on our little switch signal that as the electric shock is weakened the disk moves in a smaller and smaller circuit, showing the contractions to have become correspondingly feeble.

Now I submit to you that this is a remarkable engine whose fuel is stored up in, and is apiece with, its working gear; and a strange explosive substance the violence of whose action can be regulated at will. You have before heard that the smoothness and duration of our own voluntary movements are due to the fusion of many single momentary muscular contractions. You can now understand what was not clear before, how we can call upon our hands to make those motions whose delicacy and variety no artificial machine can imitate.

We see then that the muscle alone when cut out of the body is probably able to reproduce all the movements which it can undergo in the body. But it has appeared that the muscle at rest always remains so unless stirred up by something outside itself. It is like a steam engine with steam up but throttle closed, doing no work, and if no hand turned the throttle lever it should remain forever immovable. How then are all our muscles in the various parts of the body brought into action at will?

If you were to dissect an animal, there should be found a slender white cord attached by one end to each muscle; the cords from different muscles are gathered together in bundles, and thus all take their course toward the skull or backbone, and, running through holes in their thick bony walls, finally unite with either the brain or the spinal marrow. These two great nervous masses, the brain and spinal marrow, are united with each other through a hole in the bottom of the skull. Together they form the so-called central nervous system, which is, as you see, securely sheltered from harm by the hard bony walls of the skull and backbone.

The white cords which have been mentioned are the nerves, and they connect together the central nervous system with the muscles over the whole body. If you cut in two one of these nerve-trunks in the living animal, all the muscles to which those nerve fibres run will be paralyzed and the animal incapable of moving them again. So it seems clear that whatever stirs up the muscle to activity in the body must pass along the nerves, though these show no signs of disturbance.

It is easy to prove, in fact, that the nerves do conduct impulses which cause the muscles to contract. For you see that by passing an electric shock through the nerve which is attached to our switch signal muscle we can get on the muscle all the effects that came out when it was directly excited. In this case we have used only the nerve going to one muscle; but it is evident that if I excite a large nerve-trunk containing in one bundle fibres for many different muscles, each of these muscles shall be independently excited so that all shall be made to contract. You see thrown upon the screen the legs and rump of a frog whose body trunk has all been cut away except the nerves which connect the legs with the spinal marrow. When the electric current is applied to different parts of these nerves you observe that the animal, what there is left of him, is thrown into remarkable contortions.

Without doubt, then, something descends the nerve and excites the muscle, though we see no more sign of activity in the nerve itself than we do in a telegraph wire along which a message is passing. The nerve bears somewhat the same relation to the muscle that the fuse does to the dynamite charge used in blasting. The nerve is set on fire, as it were, at the spot excited, and this chemical change or burning passes down the nerve like fire in a fuse. If I tie a string tightly around the nerve, its ignitable substance is divided by the string into two parts, and it is seen that the nervous impulse is blocked by the string, for a shock applied to the nerve beyond it has no effect on the muscle, while when the nerve is excited between the place tied and the muscle the latter responds as before. Just in the same way, if you soak with water a fuse at a point between the fired end and the dynamite, the fire cannot get to the charge.

You have *seen* that the muscle is *excitable*, and that it is also *contractile*. You have been convinced, perhaps no less surely, that the nerve is *excitable*, and that it is also *conductive*. Now the nerve is simply a message-carrier, and the muscle is simply a worker. Our nerve-muscle cut out of the body could never move or show any signs of life of itself.

But we not only move at will, but can regulate the strength and duration of our contractions to a wonderful degree. Not only that, but the different muscles supplied by different nerves may be made to move together, or one after the other, as accurately as the parts of a working engine.

We may look on the body as an army of which the muscles are the soldiers, and the nerves the aides-de-camp who carry messages to the different divisions. A good soldier never moves until commanded to do so, and thus we have them working in the body singly, or in squads, or in brigades together. This activity of the muscles goes on so that each muscle, like the soldier, works not independently, but in a manner to help the others to accomplish some definite purpose. What and where is the general whose commands set this army into action? In what part of the body does this wonderful directing power reside? You will rightly conclude that it is in the central nervous system, the brain and spinal marrow, from which we have seen that the nerves arise. If you were to study the brain or spinal marrow with the microscope, you would find in it great numbers of tiny bodies called nerve cells, some of whose forms are shown in Fig. 8. Nerves on entering the brain and marrow no doubt unite with these nerve cells, and the various cells are connected together by their long branches. Now it is within these nerve cells, without doubt, that all the plan of action of the body is laid down, and from them messages are sent out along a multitude of different paths to stir up the muscles to

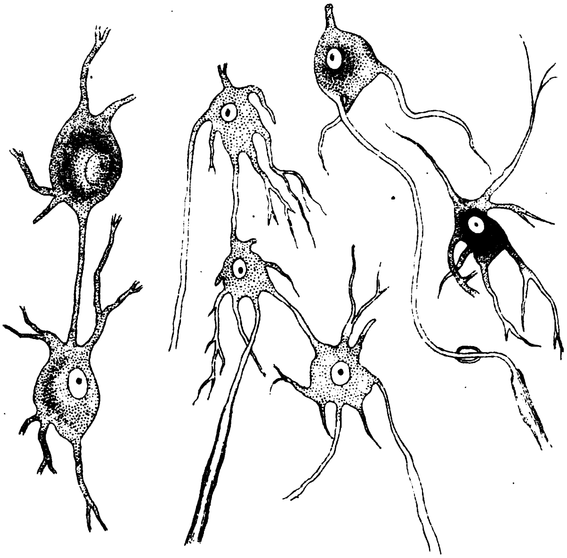

FIG. 8. Forms of nerve cells, highly magnified.

accomplish some purpose. *They* are the generals whose commands the army of muscles obeys. As the nerve cells are so small and crowded together it is impossible to excite them one by one, and so find out what their special activities are, as can be done in the case of single nerves. But it is easy to show that they act in a special way. When I cut or shock a nerve once, the muscle supplied by it contracts but once, and the number and strength of contractions can be regulated at will. But if I cut with the scissors through the back of this headless frog, and so mangle and excite its spinal marrow, you will see the contraction that succeeds is long continued, involving many muscles, showing that though the outer disturbance has ceased, the nerve centres are still in a state of excitement, and are sending out impulses which stir up the muscles. Pretty much the same sort of activity you have seen in a chicken which jumps around for a long time after its head has been cut off.

We have traced now all the movements of the body up to the central nervous system, and can feel pretty sure that it is the nerve cell which sends out all the messages that the muscles obey. But these nerve cells are shut away in a bony prison, safely removed from the chance of accident. If these cells are the regulators of the bodily machine, how is it that they come to know of outer danger in order that they may command the muscles to prepare to meet it? How do they know when it is cold or wet, light or dark, that they may tell the body to change its clothing or to go to bed? In order to explain this, I shall have to describe another set of nerves that arise in the spinal marrow and brain, but instead of going to muscles, go to terminate in parts of the body which come into contact with the outer world. These nerves are just like the ones we have became acquainted with, except that they conduct nervous impulses *to* the nerve cell instead of *from* it. They are called sensory nerves, because they lead from sense organs. For example, the eye contains sense organs that are excited by light, the ear by sound, the skin by heat and touch, the tongue by taste. So that you see if there be a sound in the air the ear nerve is excited, and its activity is transmitted to the brain; and the brain cell, by a faculty which we cannot in the least understand, may act on the information so conveyed to it, and cause the whole form and position of the body to be changed, or the cell may compare that information with messages from other sources, as the eye or skin, and allow the body to remain quietly at rest. Thus, if a man walking in the grass of a rattlesnake region hears a loud whir-r, he feels uncomfortable, and has a decided impulse to spring back; but if he looks and finds the noise is only made by a locust, the sensation derived from the eye is compared in the brain cell with that coming from the ear, and all alarm vanishes.

Some sort of relation between sense organ and nerve centre as that represented in Fig. 9, is supposed to exist in the body.

Here is a frog whose head has been cut off. The creature remains perfectly motionless, and would forever remain so if undisturbed. But when a piece of paper which has been dipped into weak acid is put upon its flank, you see that violent efforts are made to wipe it off with the feet. Now suppose I run a wire down through the spinal marrow and break it up; after some convulsive movements, the frog becomes perfectly quiet. Now apply the acid and the frog makes not the slightest motion. What has happened? The skin, nerves and muscles have not been injured in the least; they are still alive. The skin is still excited by the acid, and sends up its messages toward the marrow; but the nerve cells there have been destroyed, so there is no authority that can receive or act on information received.

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The living body has been well compared to the system of government in a country. The brain and spinal marrow are the central offices at the capital. The sensory nerves are the telegraph wires connecting the capital with lookout stations all along the coast and frontier, which stations represent the sense organs, the eye, the ear, the skin, etc. Information of a storm or of an invasion by the enemy is received at one of these stations, and the message is telegraphed to the capital, and here that telegram is compared with others constantly arriving from all over the country. It is then decided by the executive what must be done, and so messages may be sent out ordering this or that collection of troops—which, in the body, are the muscles—to go and do this or that, the commands being always intended to accomplish the greatest good for the whole organism.

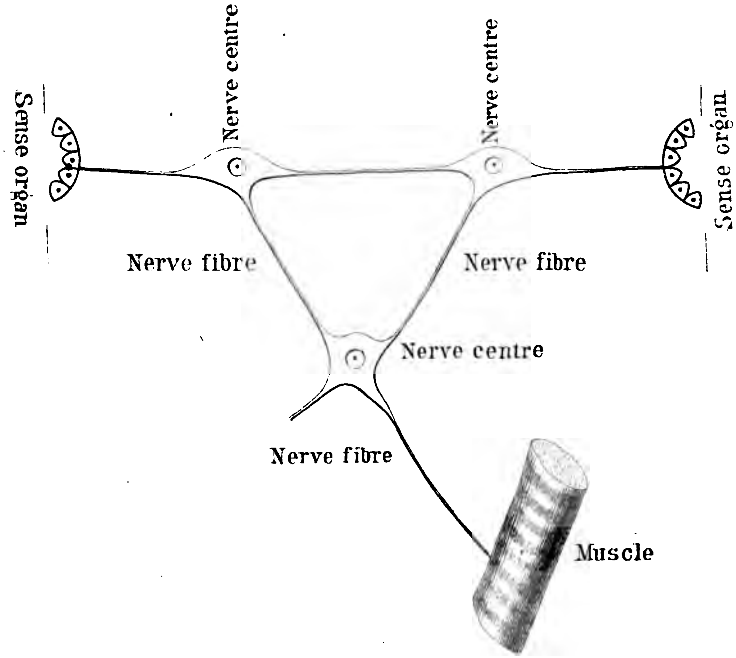

Fig. 9. Illustrating the manner in which the sense organ, nerve fibre, nerve cell and muscle are connected together in the body.

III.

ON FERMENTATION.

ON FERMENTATION.

By W. T. SEDGWICK, PH. D.

Associate in Biology, Johns Hopkins University.

I hesitated a long time before finally deciding to speak to-night on fermentation, for fermentation is caused by such little things, and by things which look so much alike, that I cannot show you many pictures, nor give you many experiments.

Twenty years ago fermentation was not thought to be a very important subject, and at that time perhaps it would not have been wise to give a public lecture upon it, for the little that was known would not have been of special interest to you and me.

About 1860 however, while we, in this country, were spoiling for a fight and were getting ready as fast as ever we could to hew each other into pieces; while we were racking our brains to invent deadly guns and machines for destroying human life, some of the best scientific men of Europe were patiently studying fermentation, and learning how to save human life. While we were passing through a bloody war, they laid the masonry and built the bridges over which we now walk almost boldly into the mysterious regions of fermentation, putrefaction, disease and death.

We all know very well how the introduction of the telegraph and the steam-engine has laid open vast fields for work, and has brought face to face nations which before were almost total strangers; and I hope to show you to-night that in much the same way the introduction of a new theory of fermentation about twenty years ago has gradually opened up to scientific men a new country peopled with strange things, and has given us a clue to many mysterious problems of life and death.

To-day we know why yeast is useful to the housewife and to the brewer; why sweet liquids get sour if we leave them in the warm air; why canned fruits spoil, after the can has once been opened, unless quickly eaten up; and why preserves are pretty sure to keep if made "pound for pound." Better yet, we are beginning to know why some diseases are contagious, and what causes relapsing fever, splenic fever, consumption and so on. Best of all, we know why we vaccinate for small-pox, and why, if well done, vaccination protects us against that loathsome disease; while we have bright hopes that some day, not so very far off, we may be able to vaccinate for some other diseases as we do for small-pox, and so may save many human lives.

As it is a good plan to begin on solid ground, we will take up first a common example of fermentation, *the alcoholic*, or *that fermentation which gives rise to alcohol and carbonic acid.* Let us recall something with which we are all familiar, and study the fermentation of the juice of an apple.

An unripe or green apple is hard, sour, "puckery," and not tempting, but as it ripens a remarkable change comes on. It gets mellower, pulpy and sweet, or pleasantly acid—very unlike its hard, puckery self of a few weeks before. Now even the sourest ripe apple contains *sugar*, and as sugar dissolves easily in the water or juice of the apple, that juice is often sweeter to the taste than the apple itself. Sweet cider is nothing but apple-juice, and as it comes from the press it is a mawkish, insipid fluid, very sweet and always containing a great deal of *sugar*. It is this sugar which makes it sticky and sweet, and attractive to boys and insects. The sweet apple-juice or sweet cider, as it is now called, is next put into a cask, and the plug or bung is left out, so that the air has free access to the contents of the cask. By the next day a curious thing has happened: at least it would be curious if we were not so familiar with it; for curiosity depends a good deal upon novelty. The taste of our apple-juice has changed and is less sweet, while a peculiar pungency or sharpness is beginning to appear. Moreover, on looking further we see bubbles of gas coming off, and if we let a light down into the cask (but not into the liquid) it will go out, proving that the gas is not air. Now this change of the apple-juice from a smooth, sweet liquid to one stinging and not sweet, is caused, we say, by the *fermentation* or *working* of the apple-juice.

Is the apple-juice then prone to ferment or change? Has it a *tendency* to go to pieces? Or has something gotten into it and done this thing? These questions bring us to the very heart of the matter, and we must stop and reflect before we answer them. One at a time, however; and first let us see what this change is which we have noticed.—A sweet liquid (apple-juice) has grown less sweet, is giving off bubbles of gas, and is becoming very biting to the taste. Now if the sugar be weighed before fermentation has set in, and if this gas and biting liquid are collected and weighed, they together will be found equal in weight to the sugar, or very nearly so. And we can prove by chemical analysis that the gas is carbonic acid gas, and the stinging liquid alcohol. While at first the sugar was present and there was no alcohol or carbonic acid, now the conditions are reversed. In fact sugar has been changed gradually into carbonic acid gas and alcohol, and *this is alcoholic fermentation—the changing of sugar into alcohol and carbonic acid gas.* Now we may ask is sugar prone to ferment? Is it always breaking up *of its own accord* into these two substances, or is it broken up by something outside of itself? We know that dry sugar in lumps or grains keeps well enough. Hence it would seem that the sugar is sufficiently firm, and is not, as might be supposed, always tumbling over and breaking up into alcohol and carbonic acid.

If, however, we dissolve some sugar in water and leave it in the air, the sweet liquid very soon sours. Perhaps dissolved sugar is more unsteady then, and the water breaks it up. But this cannot be, for we all know that sweet apple-juice, so long as it is inside the apple, never ferments; and we know, too, that canned fruits and preserves have much water and sugar in them, yet they never ferment if well prepared and kept closed, though they do so very soon if opened. Thus it is clear that sugar is not prone to break up of its own accord, and that mere water does not make it sour or "work." We have not yet looked far enough. If it is true that sugar does not of itself split up into alcohol and carbonic acid gas, it must be broken up by something external to itself, somewhat as a block may be split into chips by an axe; and perhaps a microscope might show us something in cider—some axe—which is capable of so splitting up sugar.

If we put a small drop of "working" cider under a powerful microscope we find in it a good deal of *yeast;* and we know very well, on thinking it over, that yeast turns sweet flour into sour dough, and changes sweet barley-juice into foaming alcoholic beer; so that we must ask at once, What is yeast? Does it split up sugar? If so, how could it have gotten into the cider? And is yeast the cause of that queer splitting up of the sugar of the apple-juice into alcohol and carbonic acid gas which we have noticed and have called alcoholic fermentation?

First, *What is yeast?* We know that baker's yeast is a milky-looking liquid with a muddy sediment at the bottom; and 200 years ago nobody knew any more than that about it. About that time however (1680), a bright Dutchman named *Leeuwenhoek*, a maker of fine instruments, made a microscope which was better than any which had been used before, and of course he looked at almost everything. He looked at blood which till then had been supposed to be a red liquid, and found that it was really a colorless liquid in which red bodies were floating; very much as these cranberries float in the water of this big tube which I hold in my hand.

[A tall measuring glass having a bore of about two inches, and partly filled with water and cranberries, was so held before the audience as to make the mass flow from one end to the other, and produce a tolerably red mixture which, on standing, separated into a red and a colorless layer.]

He also looked at putrid water, and found what he took to be animals; very minute, wriggling, worm-like things. Finally, he turned his glass upon yeast, and found that even the liquid portion was no more a mere liquid than the blood, but was really a colorless fluid filled with milky-looking grains; very much as if I had had small white beans instead of cranberries in that tall tube with the water.

Leeuwenhoek did not know what these grains were; but a century later, about the time when George Washington was our President, an Italian named *Fabroni* said he believed them to be alive; in fact they seemed to him half vegetable and half animal, or *vegeto-animal* in their nature. Fifty years more went by, and better microscopes had been made when, in 1837 (about the time Van Buren succeeded Jackson as President), a Frenchman, *Cagniard de la Tour* by name, went to work upon these grains, and found them budding and growing! He at once said that they were living plants, and many people began working upon this curious microscopic vegetable; till to-day, with yet better microscopes, we

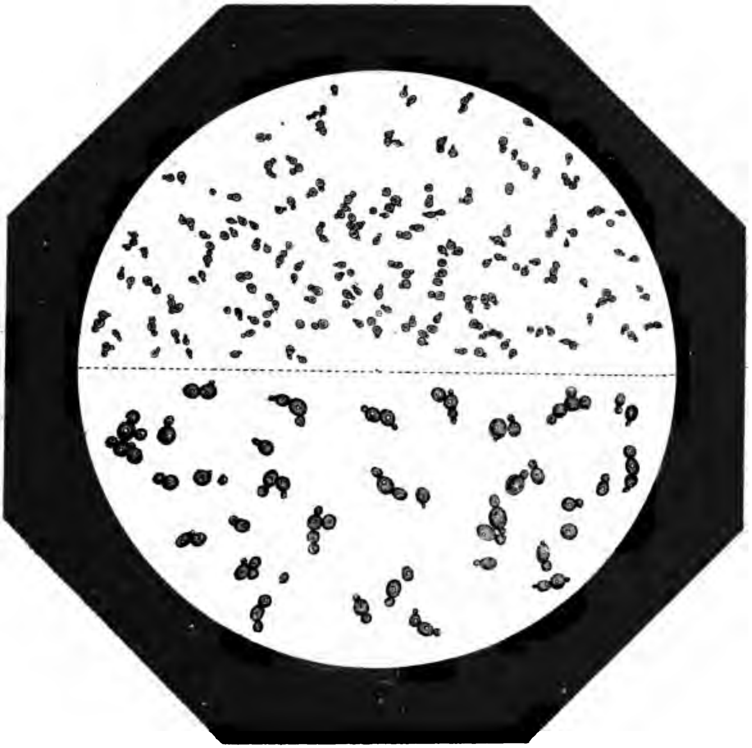

Fig. 1. Yeast-plants as seen under the microscope. In the upper half, moderately —in the lower half, highly magnified.

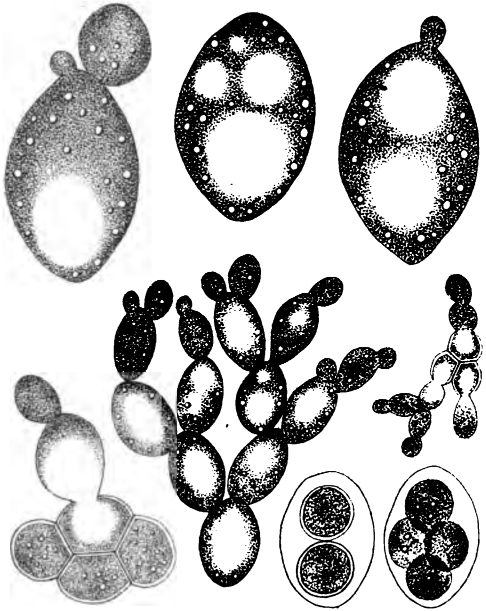

Fig. 2. Yeast-plants very greatly enlarged, and showing budding, colonies and the formation of internal spores (endogonidia).

know beyond question that yeast is a liquid swarming with myriads of curious little plants, all much alike, yet of varying sizes and shapes. [A large diagram hanging behind the speaker was referred to, and single cells, chains of cells, and budding colonies were pointed out.] (See Figures 1 and 2.)

Having discovered that yeast is a little plant floating in a liquid, we are now ready for our second question: *Can yeast split up sugar into alcohol and carbonic acid gas?* In order to waste no time, I have prepared an experiment by which I can answer that question very quickly here before your eyes, and can prove what I say.

[A large flask of actively fermenting sugar solution previously charged with yeast stood on the left of the speaker, and from it a bent tube led off and finally down into a vessel of pure water. From the end of the tube beneath the surface of the water, bubbles of gas could be seen escaping and rising to the surface. On his right was a glass retort resting upon a copper water-bath heated by a spirit-lamp.]

In this large bottle or flask I put yesterday a rather strong solution of cane-sugar in water, then I added some baker's yeast, and set the flask aside in a warm place. To-day bubbles of gas were coming off, and I have attached this bent glass tube so that the gas in order to escape has now to bubble through the pure water which you see. Let us return for a moment to the apple-juice. That, too, was sugary at first, but by the next day was giving off bubbles of gas, and we found by our microscope that there was yeast in the cider (though we did not, as we did in this case, put it there). We know that in the sweet apple-juice the sugar particles are somehow divided into bits of carbonic acid gas, for one thing, and alcohol for another. Moreover we suspect that yeast has done the mischief, and we have therefore set a trap for the yeast, have given it a supply of sugar, and are going to see if carbonic acid gas and alcohol are given off.

If they are we must charge the fermentation of apple-juice to yeast, and then will be the time to ask where the yeast came from. Here is the yeast perhaps already in the trap, for a gas of some kind is certainly coming off. Now if I let a lighted candle into this vessel (but not into the water), I shall be doing just what we did with the cider cask. In that case the flame was extinguished.

How will it be now?—As you see, the flame flickers and goes out. But let us try another test. Carbonic acid gas will dissolve in water very easily; hence if this gas is really carbonic acid gas, the water must hold a good deal of it in solution, for it has had the gas bubbling through it for some time; and if to the colorless water I add this colorless liquid, known to chemists as barium hydrate, we shall know at once if that gas has been dissolved, for if it has we shall see a heavy white cloud in the water. . . . . You see the cloud; and so we have *two proofs* that *carbonic acid gas is really given off from sugar under the activity of yeast.* But you will ask, *Is alcohol also given off?* Let us see.—In this retort was placed, before the lecture, a lot of the liquid remaining from just such a fermentation as is now going on in that flask from which carbonic acid is coming off. In other words, the residue of a sugar solution which had been fermented by yeast and from which many volumes of carbonic acid gas had escaped (as you see it escaping now from the big flask) was put into this retort. Now the retort is a little still, and if any alcohol is in that residue it will be distilled over into the tube of the retort, and then cooled and condensed so as to fall in drops from the open end. Even while I have been speaking you have perhaps seen it dropping, and here in this vessel, into which the drops have fallen, is quite a quantity of it.

I must now prove to you that it is really alcohol, which I will do by burning it. That bright blue flame, brilliant and hot, is proof enough that *alcohol as well as carbonic acid gas is given off when yeast acts upon sugar dissolved in water.* Hence we are justified in believing that yeast also causes the sugar in apple-juice to split up into alcohol and carbonic acid gas, but we cannot be absolutely sure till we make one more experiment.

If we can remove the yeast or kill it without changing the sugary liquid, then you must admit that we shall see certainly whether or not yeast really makes this curious change which we call fermentation. For if that liquid will "keep" in the absence of living yeast, and will always ferment when living yeast is in it, then yeast must be the axe which splits it—the true *ferment.* Now if we boil yeast we always kill it; but if we boil sugar solution or sweet cider, or fruit which we wish to preserve, we do not harm or alter the sugar. Therefore if we boil sugar solution or sweet cider and seal it while still hot we shall have a capital chance to see if yeast is the ferment, for all the yeast will be dead and yet the sugar will be there.—You know that cider or sugary fruit prepared in that way and kept sealed never ferments. *Hence yeast must be the axe that splits the sugar.* If any one still thinks that the heating has changed the sweet juice so that it will not ferment, let him open a jar of canned apple-juice or fruit, and in two days it will be swarming with minute living plants,—will be fermenting, and the sugar will quickly be split up into other things.

Let us now pause and see what we have learned up to this time by our study.

We know from observation and experience that sweet apple-juice contains sugar, and when fermentation sets in that it loses the sugar and gets in its place alcohol and carbonic acid gas. The chemist tells us that the sugar is a complex body, and that it is somehow broken up into these other products. Our experience teaches us that it does not of itself fall to pieces any more than a silver dollar of itself falls into two halves; we therefore look about us to see what has split the sugar, and the microscope shows us yeast (among other things) in the fermenting fluid. Remembering that yeast often makes sweet things sour, we suspect that yeast may be the ferment—the axe which has split the sugar, or the agent which has changed the silver dollar into two halves. We then set a trap for it by giving to some active yeast a supply of sugar; and, sure enough, instead of the sugar we found by-and-by a quantity of alcohol and carbonic acid gas! Feeling now almost certain that the yeast is the ferment, we kill it without altering the liquid and find that the sugar never ferments so long as we keep living yeast away. Hence we become absolutely *sure* that *yeast has broken up the sugar and changed it into alcohol and carbonic-acid gas. This interesting change we call alcoholic fermentation, the thing (yeast) which produces fermentation being called a ferment.*

Yeast, then, is a ferment, and we must study it more closely to see what it is and how it works. We have learned that it contains a growing, budding plant floating in a liquid. Is the liquid the essential part of the ferment, or is the plant the true ferment, or are both liquid and plant requisite to cause fermentation?

A very distinguished German professor named *Helmholtz* settled these questions in a way which you will easily understand. If I were to walk with perfectly water-tight leather boots in very wet sand, even though there were no holes in the boots, some moisture would come through and dampen my feet; it would come through invisible pores in the leather—pores too small to admit sand, but big enough to let in minute particles of water. Or, if I pour water upon the earth in an unglazed earthen flower-pot, the water may "soak" through and stand on the outside, though the dirt will not. Helmholtz divided a vessel into two parts by a partition of a thin, porous membrane, like leather; and on one side he put a quantity of yeast, which was like the wet sand; the yeast-plants being the grains and the liquid portion of yeast the water of the sand. On the other side of the membrane he put sugar solution.

Here then was a test: the *yeast liquid* could go through the membrane and act, if it chose, upon the sugar; while the *yeast plants* could not go through. Therefore, if the liquid fermented, it would prove that the yeast plants were not necessary to cause fermentation. In point of fact it did not ferment; hence we know that *it is the yeast plant which causes fermentation, and that the liquid portion of yeast is not able to produce fermentation.*

How does the yeast plant cause fermentation? How does it split up sugar?

These questions take us into regions beyond the reach of the keenest eye aided by the most powerful microscope. The yeast plants and the particles of sugar are so small that we cannot see *how* the plant tears the sugar into pieces. Chemistry has, however, taught us that sugar is a complex thing, even when its particles are too small for our eyes to grasp, and that a little particle of sugar is just as complex in its real nature as a big one.

Several *theories* as to the way in which yeast works have been brought forward, but I shall give you but two of them. *Liebig*, the celebrated chemist, believed, even till his death some ten years ago, that sugar particles are rather topheavy and unsteady—easily broken up into alcohol and carbonic acid. He believed that living yeast is always in an active state, its particles in rapid motion; now, the sugar being dissolved, is on all sides in contact with the yeast, and is, therefore, constantly receiving blows and shocks from the whirling particles of the yeast vegetables. Hence it is upset, it breaks into two simpler things, and the carbonic acid gas goes off in bubbles, while the liquid alcohol remains. This theory was very ingenious, and being held by a chemist so distinguished, was not easily overturned. But there was one test which finally overthrew it. Liebig's theory required that *all* of the sugar should be split up into simpler things; and for a long time it was believed that it did, all of it, split to alcohol and carbonic acid, as I split this "card" of biscuit.

[A baker's card of biscuit was shown, and split into two unequal parts by the speaker.]

About 1860, however, a now distinguished Frenchman, *Pasteur*—of whom you may never have heard, but whose name your children may some day reverence—made very careful analyses and found that the sugar is not divided in that way, but that about four or five per cent. of it becomes glycerine, succinic acid, etc., and that a still smaller portion cannot be found. It was as if I should break this card, having, say one hundred biscuits in it, into two big parts—together making up ninety-five, and standing for the alcohol and carbonic acid—and four or five single biscuits, equal to the four or five per cent. of glycerine, and so on, and should leave one biscuit out of sight, or should eat it up.

Now, the question arose, what becomes of the lost one per cent. —the missing biscuit? Pasteur says that that is devoured by the yeast as a kind of toll or reward for its labor in splitting up the sugar. It is easy to see that the yeast has flourished, has increased in quantity, and we believe it is on these missing biscuits that it has grown. He shows that sugar is not easily upset, and does not believe that yeast merely hits it, whereupon it straightway falls to pieces, but that *the living yeast plants take out for their own food a small bit of the complex sugar body, and that it then falls to pieces just as a whole arch tumbles if you pull out the keystone.*

We must now leave yeast and alcoholic fermentation for a time and examine some other kinds of fermentation produced by other ferments. When Leeuwenhoek looked at putrid water, as has been said, he found in it wriggling, worm-like things which he supposed were minute animals. As time went on, others saw them in solutions which were decaying or putrefying, and even so late as 1850 they were commonly supposed to be animals—one great microscopist, Ehrenberg, having in 1838 actually believed that they had stomachs and mouths! About 1860 a new idea arose, and it was found that they were not animals at all, but tiny plants, having a peculiar power of motion, and many of them furnished with long hair-like appendages, by which they were driven through the water as an ocean steamer is driven by its screw. They are so tiny that one writer believes that a space the size of a die such as is used in backgammon, would hold at least six hundreds of millions of them without having them crowded! It requires a very high-power microscope to see them at all, and that is the reason why we were so long in finding out their true nature. (See Figures 3 and 4.)

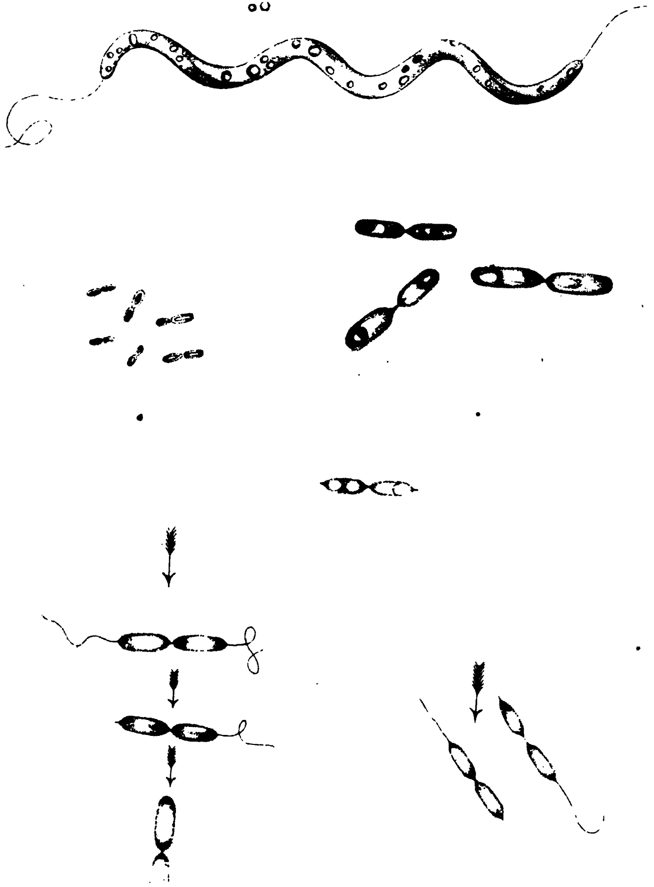

Fig. 8. Ferment-plants (*Spirillum* and *Bacterium*) enormously magnified, and showing the locomotive organs which are threads called *cilia*.

You will recollect that it was about 1860 that these were discovered to be plants; it was not much later that the new theory of fermentation—Pasteur's—came up and received so much support; so that this idea at once occurred to some: If yeast is a plant and causes sugar to break up for its own purposes—that is, for food—may it not be that these minute plants attack other substances as yeast does sugar; that they break them up in much the same way; and instead of rejecting alcohol and carbonic acid as unfit for food, they reject other things, which, in some cases, have a bad odor? In other words, may it not be that putrefaction is really a fermentation—not an alcoholic one, but a bad-smelling fermentation,—caused by little plants really ferments like yeast? This view is now very generally accepted, and we believe that putrefaction and decay, instead of being the token of death, are really the work of myriads of little living things whose food they furnish. Every decaying apple or banana, every muddy pool in which garbage lies, every damp, moist, bad-smelling spot in our homes, is probably swarming with these scavengers. But what happens when the pools dry up and when food is scarce? A very important thing happens. The plants dry up too, and many of them die, for they need moisture—and dread sunshine and dryness. Some of them, however, ripen a kind of seed called "*germs*" or "*spores*," and these are very light indeed. They are swept about by the wind, and dust is usually full of them. Untold millions are almost constantly in the air, and it is these seeds which infect canned fruits. If canned fruits be opened in air strained through cotton (which will keep back these spores and not allow them to pass), or if the air in any way be robbed of them and so be made free from germs, then canned fruits may be opened boldly and will never ferment. Purest mountain air is also very free from them, and hence its value for invalids.

Some kinds of yeast have spores floating in the air, and these are the things which made our sweet apple-juice ferment. The cask was "exposed" to the germs in the air. Yeast, however, is limited in its food. It has but a sweet tooth, and lives usually upon sugar, rejecting in a manner worthy of imitation the tempting alcohol and carbonic acid. That alcohol is tempting can be shown by a return to our cask; for so soon as the yeast has done its work and has converted all the sugar into alcohol and carbonic acid gas, it falls to the

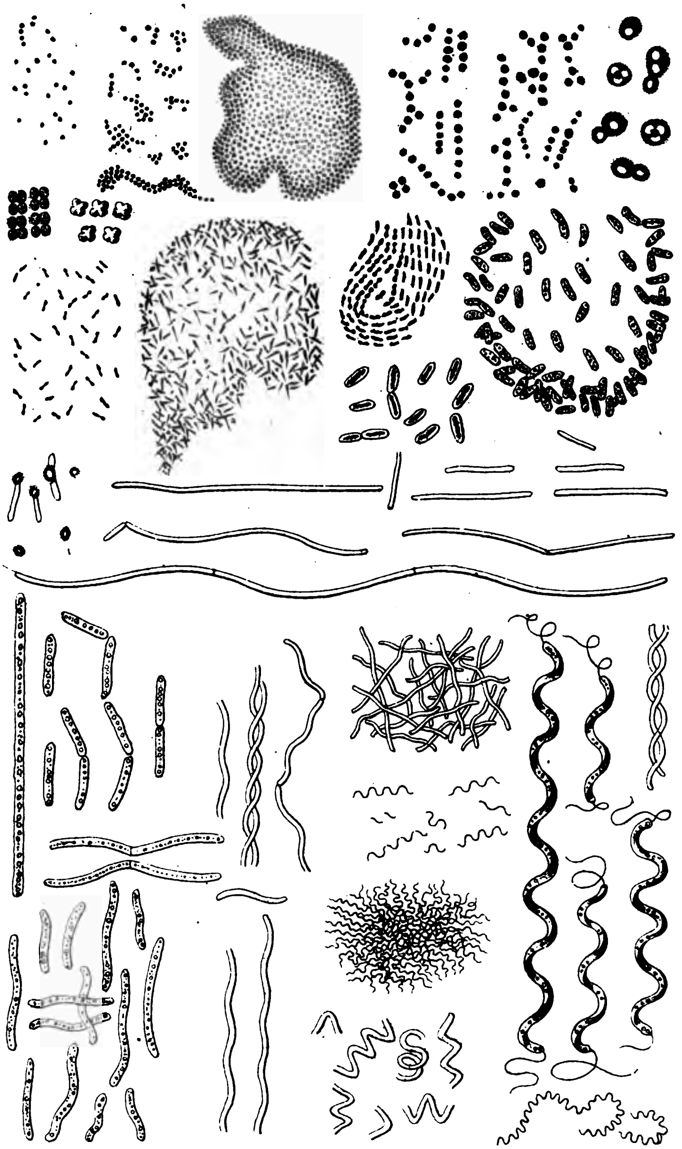

Fig. 4. Various examples of microscopic plants, some of which produce putrefaction. Those on the right near the bottom show at either end the hair-like appendage of locomotion. All are greatly magnified.

bottom of the cask and a new ferment attacks the liquid. This is the *vinegar ferment*, and it shortly converts the alcohol into acetic acid, and changes " hard " cider into vinegar. (See Figure 5.)

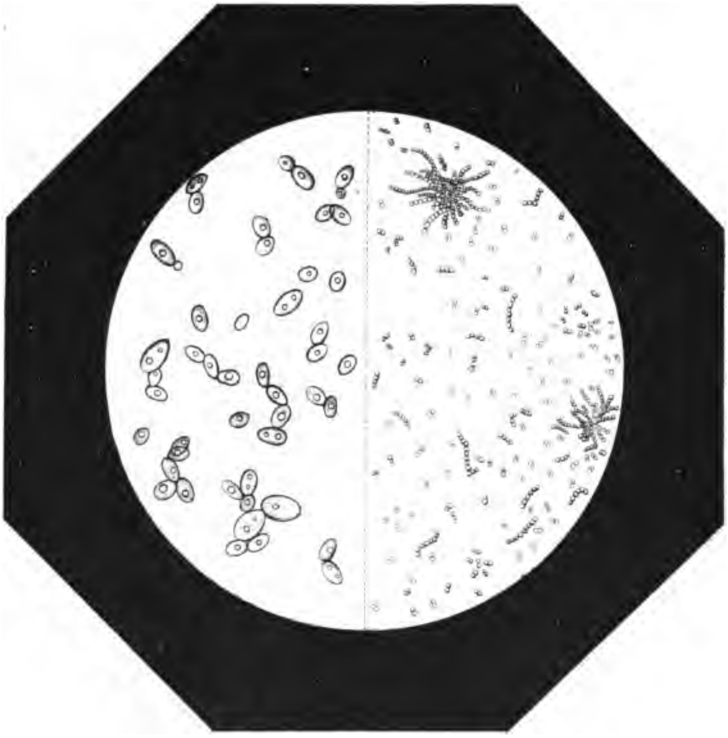

Fig. 5. The cells on the left are those of a kind of yeast found in the fermentation of wine. On the right are figured some of the minute cells of the vinegar ferment plant. They form chains which are best described as necklace-form.

Let us now look at the more practical side of fermentations.

Bread-making.—In making "leavened" bread the ferment yeast is often used to render it " light." It does this by acting, as in other cases, upon the sugar which is present in the ripe grain or flour, and changing it into alcohol, carbonic acid gas, and some other things mentioned above. The yeast having sugar at nearly every point, makes little bubbles of gas wherever it is. If it is allowed to convert all the sugar the bread becomes sour. In baking, the minute bubbles of carbonic acid are swollen by the heat and the bread becomes even lighter than the dough. The alcohol is evaporated into the air of the oven and lost. In bread-making, then, the carbonic acid gas is wanted, and yeast is used to furnish it; but that yeast is speedily baked with the bread and can never be used again. Unleavened bread is dough baked without yeast or powders, and is never "light."

Beer-making.—In making beer and bread the sugar present in ripe grains is used, while in cider-making and wine-making the sugar of ripe fruits is employed. In bread-making we use rye, wheat, etc., and in beer-making the brewer uses barley. He first lets it sprout a little, because the growing grain has more sugar in it than the merely ripe grain. But when it has gotten very sugary he roasts it and stops the growing; the grain is now called malt. This sprouted sugary grain having been ground up and mixed with water, hops, etc., is called *wort*, and is ready for the ferment, yeast; this having been added, fermentation (the change of sugar into alcohol and carbonic acid gas) begins. Finally, as you know, the sugar is mostly changed into alcohol and carbonic acid, and we have essentially, beer,—a liquid pungent from the presence of alcohol and full of bubbles of carbonic acid gas.

Wine-making.—In using grape juice, which is very sweet, the wine-maker does not add yeast, but its spores get in from the air. It is true yeast, but is unlike the brewer's yeast in some respects. A grape inside its skin seldom or never ferments; it is hermetically sealed by its skin, but the "bloom" of the outside of the grape-skin is full of ferment germs awaiting an opportunity to feed upon and so to ferment the sugary juice inside. (See Fig. 5.)

Souring of milk.—Milk placed in a warm room and exposed to the germs or spores in the air speedily sours. Now milk, too, contains a kind of sugar which gives it pleasant sweetness, and it is the change of this sugar which makes it sour; for instead of being changed into alcohol and a gaseous acid, it is changed into a liquid acid called *lactic acid.* This change, too, is caused by a ferment plant, but not by a true yeast. *Why do we set milk in a cool place or upon ice, to save it?* Simply because in that way we check the growth of the ferment, and growth of the ferment plants means fermentation. If a geranium or a rose-bush were put upon ice or in a cold cellar it would not grow; no more will a ferment-plant; it does not change its nature because it is small. *Why do we scald* *milk or other things about to sour?* Simply because boiling, as it does with yeast, will kill the various ferments and so stop fermentation. To boil a geranium would kill it, and even if new geranium seeds were soon planted from the air they would need time to develop. Ferments are plants too, and their germs need time to develop, hence we can stop fermentation for a time, by scalding. But the process must be often repeated in order to save the milk for a long time.

Preserving and Canning.—You are familiar with both these operations. *In canning*, the sweet, sugary fruits, or the meats which would easily "spoil," are put into cans, heated for a time, and *sealed up while still hot.* The heat kills the ferments present at the time, and the tight sealing keeps the spores of other ferments out. Hence there are two important steps—heating and sealing. If either is badly done the operation is useless. The "keeping" of canned meats and sugary things proves that such bodies must be acted upon from without; they never putrefy nor sour of their own accord; but if the cans be opened they spoil in a day or two—that is, as soon as the germs of ferments can get in from the air and sprout and grow. *The life of the ferment means the death and destruction of the thing it feeds upon—the thing fermented; the death or absence of all ferments means the preservation of the meats or fruits.*

Preserving is an older method of saving things which would easily ferment, and is still used for fruits. It depends for success upon a very simple fact, namely, that ferments must have water in order to grow; and a good deal of water too. They live ordinarily only in watery fluids and are themselves watery. It is as if a seed "fell upon dry ground" when ferment germs fall into "preserves," for the syrup, which itself greedily absorbs water, not only fails to supply the thirsty yeast, but actually robs it of much of the water which yeast always contains. Yeast is in this way utterly paralyzed.

"Preserves" are much more sugary than watery, and though the germs do fall into them they cannot grow for lack of water; if, however, we dilute the preserves they will swarm with ferments. Many a housewife has learned to her sorrow when too late that her preserves were not "thick" enough, which means they were too watery; too watery for preservation, but a happy hunting-ground for the ferments.

With jellies there are even fewer chances of fermentation, owing to the necessary solidity of the fruit juices.

Disease-Ferments.—About 1850 a French observer saw in the blood of animals having a certain fever, organisms which were very small and rod-like. He did not think very much about them, however, and it did not occur to very many that they were really a ferment till after Pasteur had written in 1860, or thereabouts. From that time a new theory of contagious and infectious diseases has grown up, till to-day the so-called "Germ Theory" is one of the best things we have by which to comprehend disease. It is astonishing how much likeness there is between fermentation (say of apple-juice) and some diseases. For example, an unvaccinated person is exposed to small-pox. For a time nothing happens. Then comes the fever and rise of temperature—the period of disturbance. Next comes freedom from fever and recovery, or death. So with the cask of apple-juice. It is first "exposed" to the germs in the air. Then comes a period during which little or nothing happens. This is followed by active fermentation—the sickness of the apple-juice—and a rise of temperature or its fever. Then come rest and absence of fermentation—the period of recovery.

In the small-pox the patient usually has the disease but once, very much as the barrel of cider ferments but once.

The series of events in the two cases may be put side by side in this way:

Disease—Small-pox.	*Fermentation—Apple-juice.*
1. Period of exposure.	1. Period of exposure.
2. Period of repose.	2. Period of repose.
3. Sickness of patient; fever; rise of temperature.	3. Working of the apple-juice; rise of temperature.
4. Recovery or death.	4. Cessation of the fermentation.
5. Protection (if living) from another attack of the same disease.	5. Protection from another fermentation by the same ferment.

By such examples it is easy to see how we might suppose a person suffering with small-pox to be really undergoing a fermentation. "Exposed" to the disease, he receives into his lungs spores or germs. These slowly develop, as in cider or milk, but at length bring him down; they exhaust the food upon which they thrive, and so cease to behave as ferments. The principal objection to this theory is that it is not yet proven in the case of very many diseases. In some, however, it is proven beyond a doubt,

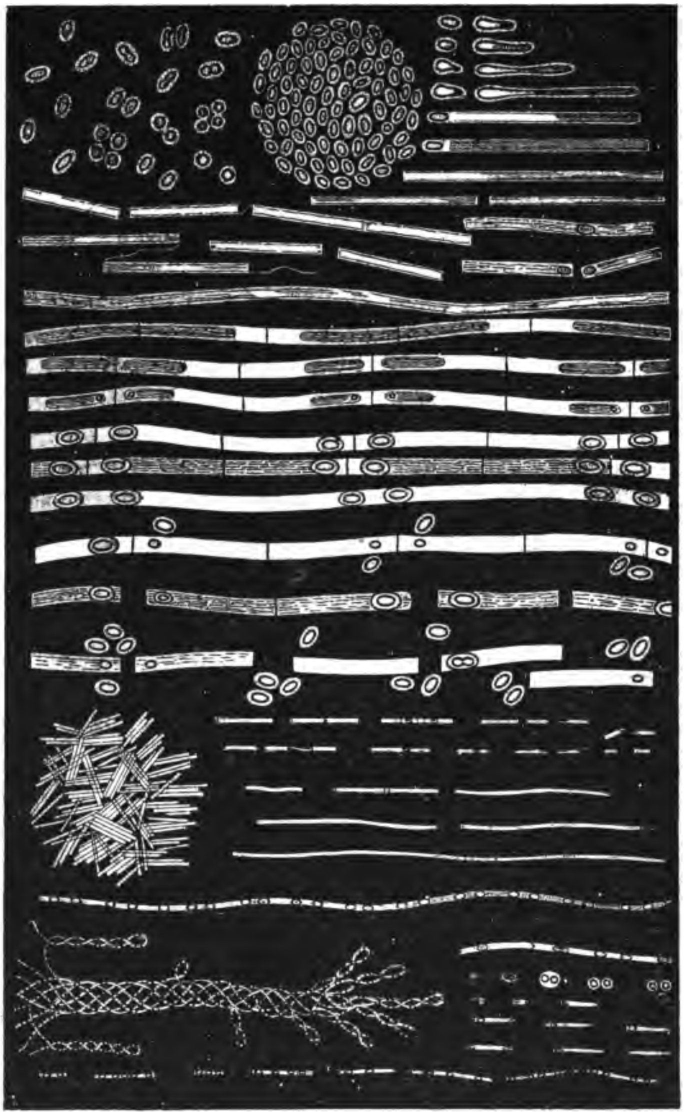

Fig. 6. The Ferment-Plant of the Splenic Fever. At the top and to the left, spores are seen, and on the right they are growing out into long narrow rods. Half-way down, spores are seen forming within these rods or tubes, and at the bottom also may be seen a similar process. (Highly magnified.)

and in two of these, spleen fever and relapsing fever, there is no doubt that we have a true fermentation caused by plant-ferments.

Spleen Fever, or Malignant Pustule.—Although it is not much heard of in this country, there is a dangerous infectious disease common in Europe (especially in Russia and Germany) called splenic fever, or malignant pustule. It attacks both men and lower animals, and has carried off thousands upon thousands of sheep, cattle, pigs and horses, besides hundreds of human beings. Now, this disease has been carefully studied, and it has been proven beyond any doubt to be really a kind of fermentation caused by a microscopic plant called *Bacillus.* This *Bacillus* is closely related to well-known ferments, and can scarcely be distinguished from them except by its behavior. They are harmless, but this one is deadly. The figures show it, very much magnified, in different forms and stages. (See Figures 6 and 7.)

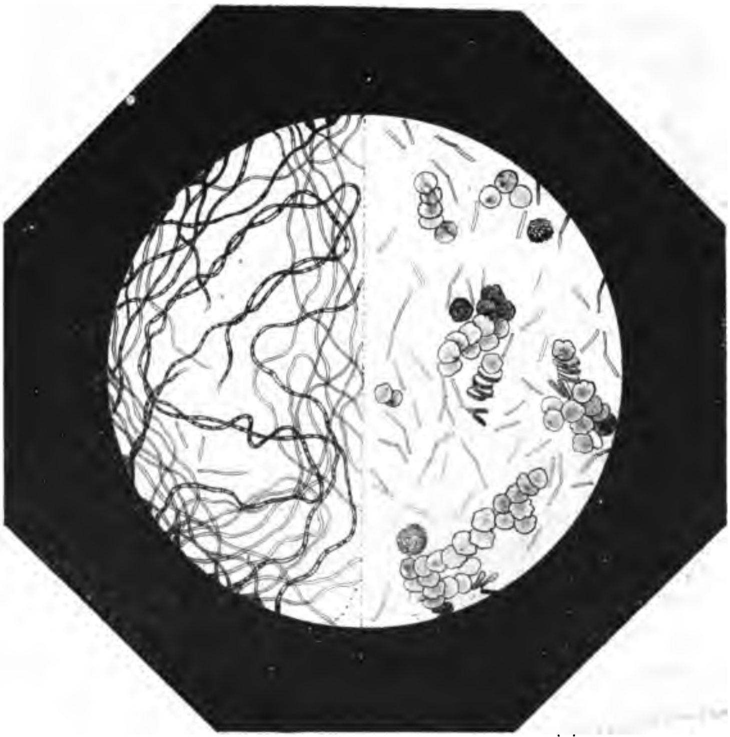

Fig. 7. Splenic-Fever Plants. On the left greatly intertwined filaments or branches, within which spores may be seen. On the right straighter rods lying amongst shrivelled blood-corpuscles. (Highly magnified.)

Relapsing Fever.—This is a peculiar epidemic fever also common in Germany and Russia, in which the patient is seized by a sharp fever which lasts about a week, and then ends with a severe sweating; after the sweating the patient seems to be getting better, when another attack comes on and behaves like the first; again the fever leaves him and again comes a relapse, till finally recovery or death takes place. This fever, too, has been studied, and its ferment has been figured and described. The disease is apparently a true fermentation, and caused by a true ferment-plant. Other cases might be given, but these must suffice.*

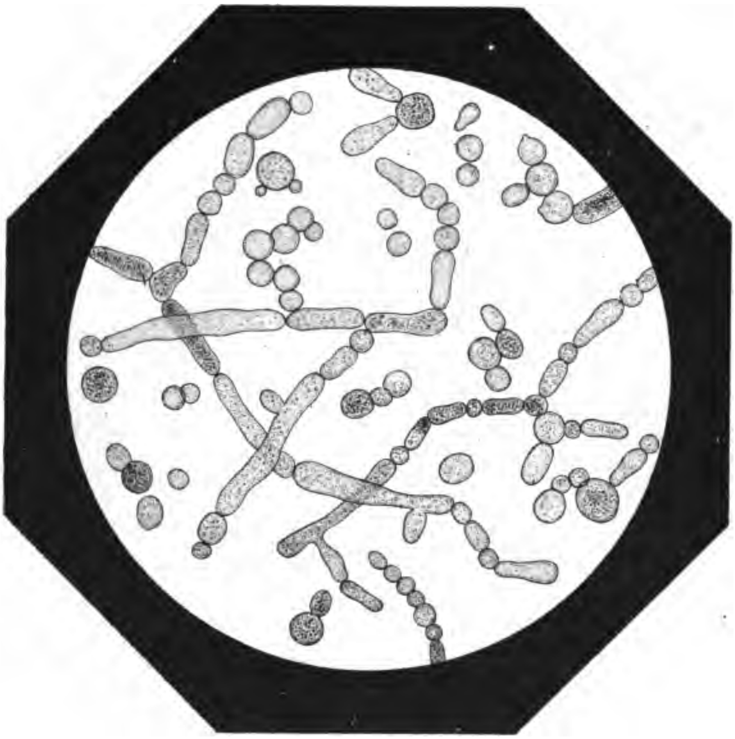

Fig. 8. A plant—one of the moulds—growing with very little air. Observe especially the long tubes and compare with Fig. 9. (Moderately enlarged.)

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* Within a few weeks of the time when this lecture was given, *Robert Koch*, the German biographer of the ferment of splenic fever, announced his discovery of a disease-ferment which produces lung-consumption. This discovery has caused intense excitement wherever it is known, and those best competent to decide are convinced that Koch is correct, and that some forms of consumption are certainly produced by this little plant. It is a near relative of that which produces splenic fever, but anything further concerning it would be out of place here.

Habits of Ferment-Plants.—One of the most wonderful and extremely important things about ferments is that they are able to change their habits of life under certain conditions. Yeast, for example, behaves very differently according to the food it gets. Like some higher forms of life it must have food, but will get it where it can get it easiest. If, however, it is partly starved by having too little air, it becomes a more powerful ferment and tears sugar to pieces much more violently. Now, if a dog is well used and is given plenty of good food, he will not be so likely to become violent and dangerous as when he is abused and gets little or no food and is always half starved. It has been found that ferments are, in regard to their food, much like the dog. If well fed

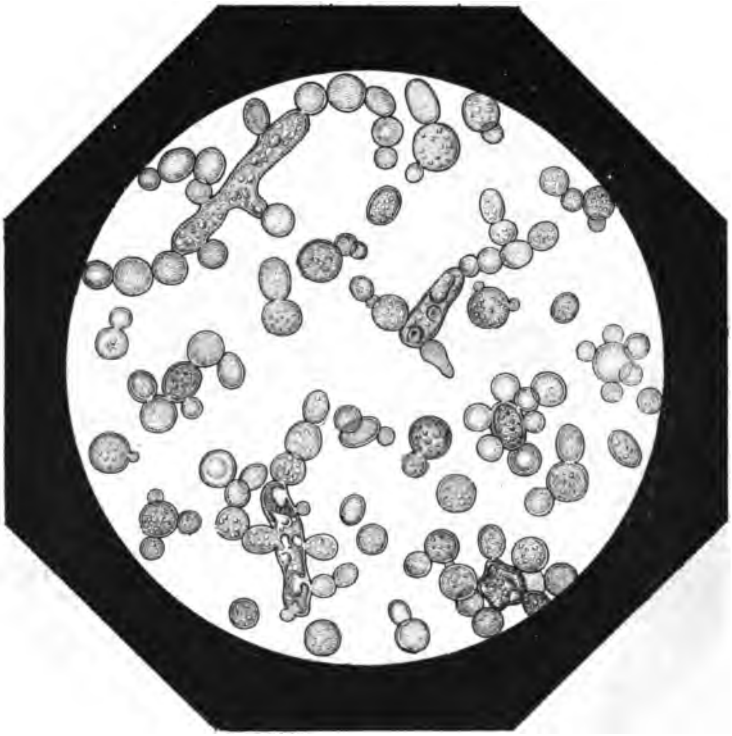

Fig. 9. The same plant as shown in Fig. 8, but growing with very much less air. Its starving condition has sufficed to change its shape. Compare Fig. 8. (Moderately enlarged.)

and given air enough they are usually harmless, but if starved too much they may become dangerous. The important point is, that *ferments may, under certain circumstances, change their mode of life.* As a kind, harmless dog may by abuse and bad feeding sometimes be changed into a miserable, vicious cur, so a harmless ferment-plant, when good food and air are taken from it, may become a deadly poison capable of producing disease and death.

Thus it is said that the common blue mould which you have seen upon jellies, jams and fruits, as well as upon old boots and damp walls, by bad treatment (lack of air and food) may become a dangerous, poisonous plant. On the other hand, precisely as a bad dog may sometimes be improved and made less dangerous by kindness and good food, so some dangerous ferment-plants may change their habits under good conditions and become less harmful.

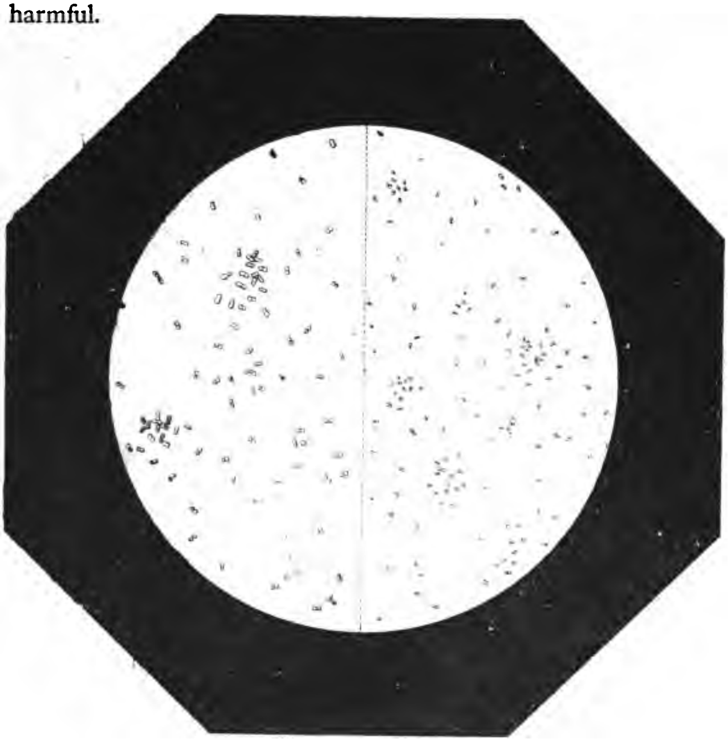

Fig. 10. **The Ferment-Plant of Chicken Cholera.** On the left greatly, on the right less enlarged.

Vaccination.—On the fact that the habits of a plant-ferment may change is based the theory of vaccination. Pasteur has lately proven that by proper care the ferment of chicken cholera may be made less harmful, and so modified that, instead of killing the fowl, it will merely sicken it and the bird will finally recover. Moreover, it is a fact that the tamed ferment-plants, though they do not kill—like the violent and poisonous ones—do eat up, probably, the foods upon which the latter would live; at any rate, after a chicken has had the mild, harmless cholera, by which it is only sickened and not killed, it cannot ordinarily have the dangerous form of the disease. Accordingly Pasteur vaccinates chickens, and though they are ill for a time—as a man is who has "a bad arm"—they do not often die, and afterwards they rarely, if ever, have the disease again. In this way many thousands of chickens have already been saved. In this way, too, sheep have been saved, and it is hoped, as time goes on, that the ferments of many diseases which afflict mankind may be cultivated outside the body—may be tamed and rendered harmless, so that finally they or their descendants may be used as weapons (by vaccination) against the severe forms of the diseases.

Finally, you must have seen that any filth, or bad air, or decaying substances may become the home of dangerous and even deadly disease-ferments. And since pure air, sunshine and clean homes are the enemies of such things, they are among our very best friends. Dirt, filth, decay and bad air may change harmless tiny plants into terrible disease-poisons; hence let us see to it that our homes are clean and pure, always full of fresh air and of sunshine.

IV.

ON SOME METHODS OF LOCOMOTION IN ANIMALS.

ON SOME METHODS OF LOCOMOTION IN ANIMALS.

By W. K. Brooks, Ph. D.

Associate in Biology, Johns Hopkins University.

I was taught at school, and I suppose that many of my hearers were also, that the difference between plants and animals is this: that plants grow, while animals both grow and move. Times change, and many things which were once thought to be absolutely true are now known to be only partially true. There are many plants which are able to move about with great activity, and I shall speak to you soon of animals which are as firmly rooted to one spot as an oak tree. Still we naturally associate the power of locomotion with the idea of an animal, and animals are, as a rule, characterized by their ability to move about at will.

I shall speak to you this evening of some of the less familiar modes of locomotion in animals. We are well acquainted with the flight of insects and birds, the swimming of fishes and turtles, and the climbing, running and walking of quadrupeds; but there are many animals which from their small size, or because of the places where they live, are less familiar to us, and among these we find many contrivances for movement from place to place which will, I think, be novel and interesting to you.

The first animal I wish to speak of is one which is able to move about freely, although it is absolutely without moving organs. It not only has no limbs, no wings, fins, arms or legs, but it has no bones, no muscles, and no nerves. It is a very common animal, but as it is invisible without a microscope, it is a total stranger to most of us. It is called by a Greek name, which may be translated the *changeable animal.* (Fig. 1.)

If a little of the green film from the bottom of a pond or ditch be placed in a watch-crystal and carefully examined with a micro-

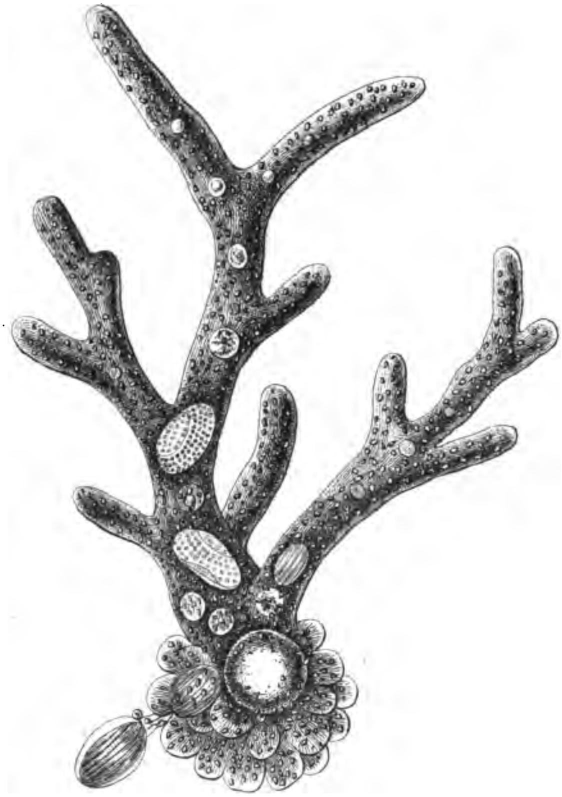

Fig. 1. The changeable animal, greatly magnified. From Ceidy.

scope, it will probably be found to contain a few little irregular, rounded lumps of transparent jelly. They may be almost perfectly transparent, or they may contain grains of sand and dirt, microscopic plants, and other foreign bodies. These little lumps are the changeable animals. For some time after they have been handled they remain quiet, and no one would suppose that they are living things; but it is only necessary to keep one of them in view until it has recovered from the shock produced by placing it under the microscope, in order to discover signs of life. As soon as it is sure that the danger is over it begins to change its shape a little, but very slowly. The outline of the body becomes irregular, and little rounded projections make their appearance around its body. These eminences grow and change slowly; so slowly that the change might easily be overlooked; but careful drawings made at short intervals show that the outline of the body is varying continually, and in a few minutes the rounded lump becomes transformed into something like a map of an irregular island, with a notched and indented coast, deep bays, and long irregular peninsulas. The outline changes continually, bays filling up and peninsulas disappearing, while others are formed in new places. After a time, when the animal has decided which way it wishes to move, one of the peninsulas begins to grow larger than the others. Careful examination will show that the substance of the body is flowing in slow, steady currents into this, and its tip gradually enlarges, until the animal is divided into two irregular islands, connected by an irregular isthmus. Soon the new island becomes larger than the old one; the remains of the latter then flow across the isthmus, leaving this as a peninsula. This now flows into the new body, and the animal has moved a step; but before this change is completed, another peninsula may grow out from some other part of the body, so that the animal may flow along in several directions at the same time. If in its travels any part of the body touches anything which is fit for food, it flows around it, as a drop of water would do, and having got it inside its body in this way, it digests it. If this food is a small animal with a hard indigestible shell, it digests out the soft parts, and then flowing away, leaves the shell behind. If it is suddenly startled by a jar, or by the touch of a larger animal, it draws in all its outlying projections, and making itself as small and compact as possible, it remains quiet until the danger is past.

This is the simplest method of motion in animals, and the changeable animal is one of the simplest living things known. The next method of motion of which I wish to speak is very simple, but it is performed by definite parts. It is motion by what may be called *swimming hairs*, and it is most easily studied in the microscopic animals known as *Infusoria*. If we make an infusion of hay or straw, or of dry moss and leaves, by putting a small quantity into a tumbler of water, we shall find, after it has stood for a few days exposed to the air in a warm place, that the surface of the water is covered with a white film. A fragment of this film, when examined in a drop of water under the microscope, is found to be made up almost entirely of small transparent animals, which are known as Infusoria from the fact that they nearly always make their appearance in organic infusions after they have been exposed for a short time to the air. They do not flow along like the changeable animal, but dart actively from place to place. They are soft and transparent, and their flexible bodies change their shape when they come into contact with each other or with hard substances, but each one of them has a definite form which it always assumes when other bodies do not prevent. One of the most common Infusoria is known, from its shape, as the *slipper* animal. (Fig. 2.) It has a long oval body, drawn out to a point at one end to represent the toe of the slipper, and rounded at the opposite end or heel. On one side there is a depression like the opening for the foot, and at the bottom of this is the animal's mouth.

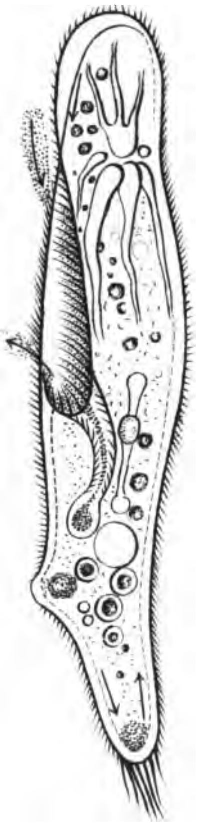

Fig. 2. Slipper animal, greatly magnified. Copied from H. J. Clark.

The slipper animal glides about with great rapidity, and changes its course at will; but when it is examined with a low magnifying power, no traces of locomotor organs can be seen. Its motions are very puzzling, for it seems to have in itself no more means of propulsion than an arrow has, and it would certainly be very puzzling to find an arrow turning to the right and left, stopping and starting again, and continuing in motion long after it had left the bow. On more careful examination we find that the fine floating particles which are contained in the water never come close to the animal's body, but that there is a thin belt of perfectly transparent water around its whole body. We find, too, that whenever a large particle of dirt approaches the surface of the body it is shot away, and these facts seem to indicate that the body is covered by a locomotor mechanism of some kind, so small and so active that it eludes observation. Finding a specimen which has got into a corner where there is not sufficient water we discover that this is the case; for as the animal grows weaker, the whole surface of the body is seen to be covered by thousands of little transparent hairs. These hairs lash the water like oars, and as their motion in one direction is more violent than the motion in the opposite direction, they act as oars to row the animal through the water. Around the opening of the slipper there is a circle of somewhat larger hairs, which are so placed that instead of moving the animal along, they drive food into its mouth.

Locomotion by swimming hairs, or as they are technically called, by *cilia*, is not confined to very simple and minute animals, but it is frequently met with in the young of higher and larger animals, even when the full-grown animal moves in quite a different way. A full-grown snail is a crawling animal, creeping over the ground by means of a flat, muscular foot. The newly-hatched young of many marine snails are able to swim with great activity, by means of an interesting mechanism of swimming hairs. When the surface of the ocean is skimmed with a fine net on a calm evening, numbers of these young snails will usually be captured. When they are placed under the microscope in a little water they draw back into their shells and drop to the bottom, so that examination at first shows nothing except a number of delicate and gracefully coiled spiral shells, lying on the bottom and apparently empty. After a time a little foot is protruded from the shell, and then a pair of feelers with eyes upon them. Soon afterwards the animal spreads out from the opening a pair of broad but very thin fans or sails, fringed with long, slender swimming hairs. As these lash the water the animal rises from the bottom and swims away. If it is disturbed by a gentle tap on the table, it instantly folds down its swimming hairs, draws in and stows away its sails, and drops to the bottom, to lie there until the supposed danger is past. (Fig. 3.)

The young oyster (Fig. 4) also swims actively by a cluster of long swimming-hairs which are arranged around a thickened pad at the anterior end of the body. The swimming life of the oyster is very short, however, and it soon loses its swimming organ and settles down for life.

The young of the starfish also swims by means of swimming hairs, while the adult has a complicated locomotor apparatus, which is so peculiar that it is well worth careful examination. Those of you whose acquaintance with starfishes extends no further than the dried specimens which are brought home by visitors at the seashore, may be surprised to learn that the animal has any power of

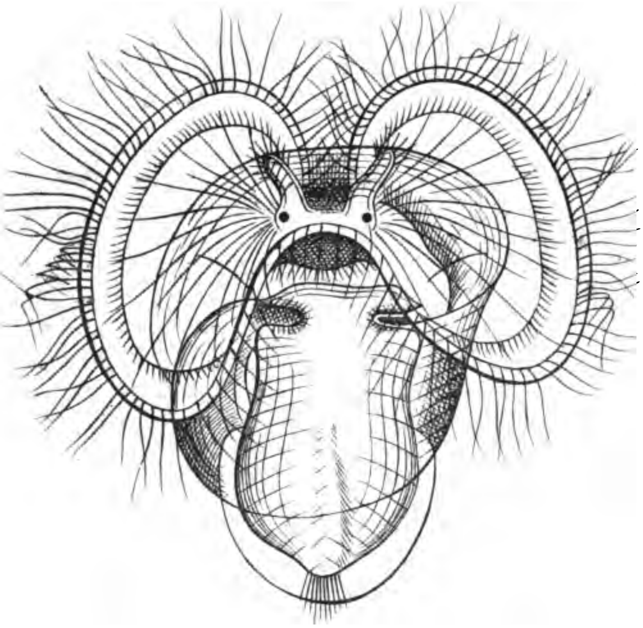

Fig. 3. A young marine Snail, swimming by the cilia around the free edge of its sail; greatly magnified. Drawn from nature by W. K. Brooks.

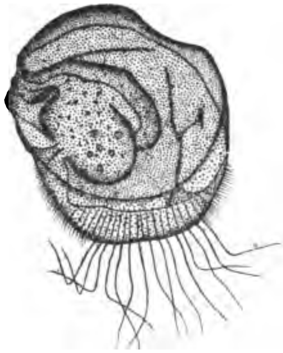

Fig. 4. A young Oyster, swimming by a tuft of swimming hairs; greatly magnified. Drawn from nature by W. K. Brooks.

locomotion, for the dried specimen appears to be simply an inflexible, brittle, stony star. (Fig. 5.) The living animal is quite different; the rays of the star are soft and can bend in every direction, and along the bottom of each ray there are two rows of long, slender, transparent feet, several hundred in each row. The feet are tubular; capable of considerable protrusion and retraction, and each one ends in a little sucker. The foot is hollow and is filled with water, and its wall contains a set of circular muscles, and also a set of longitudinal muscles. The cavity of each foot communicates, through a narrow tube, with a little muscular bladder inside the body, and filled like the foot with water. When walking the ani-

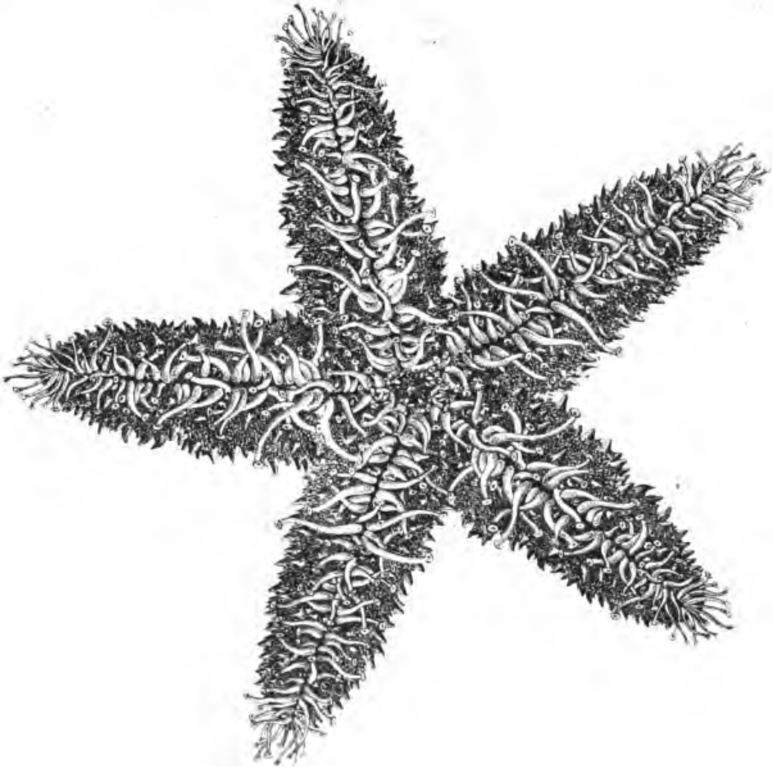

Fig. 5. Lower surface of a living Star Fish, to show the sucking feet; smaller than life. Copied from A. Agassiz.

mal relaxes the muscles of the foot, and contracting the muscles of the bladder drives the water out into the foot. It then contracts the circular muscles of the foot, and thus renders it long and slender, and protrudes it until the sucker reaches and fastens upon the surface over which the animal is moving. The muscles of the bladder and the circular muscles are then relaxed, and the longitudinal muscles contracting, the water is driven out of the foot into the bladder, and the foot is thus shortened, and the body of the animal is pulled forward to the point of attachment. The bladders and feet are supplied with water through a complicated set of tubes or pipes, which run to nearly every part of the body.

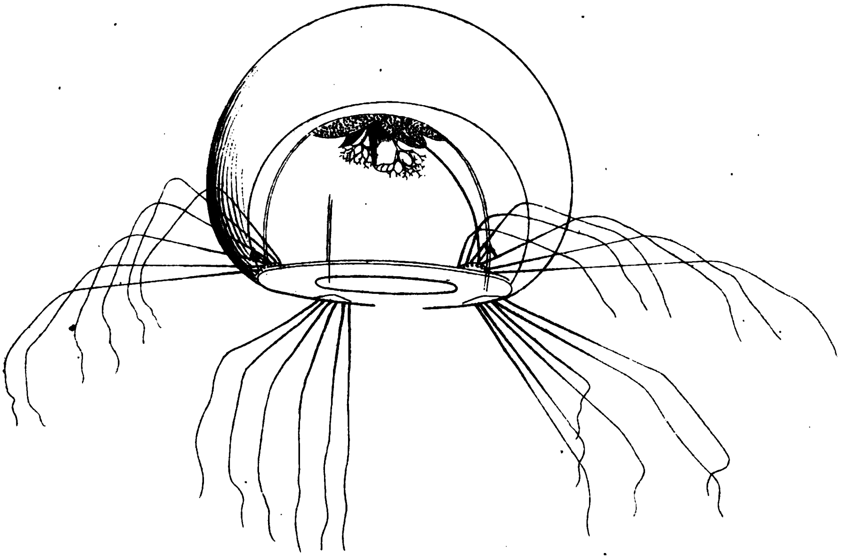

Fig. 6. A swimming Jelly Fish, slightly magnified. Drawn from nature by W. K. Brooks.

In the jelly-fishes water is employed as a means of locomotion in a different way. A jelly-fish may be compared to a flat hemispherical bell without a handle. The greater part of the body consists of a gelatinous elastic body, or *umbrella*, as it is called, and the stomach, mouth and other organs hang down from the centre of the umbrella like the clapper in a bell. (Fig. 6.) The umbrella is thin near the edge, but in the centre it is thick, and so elastic that it quickly recovers its shape after being compressed. The mouth of the bell is not entirely open, but is partially closed by a thin, flat, horizontal ring, the *veil*, which runs inwards around its lower edge. The veil is so thin that it can be pushed in or drawn out into a short funnel. On the inner surface of the umbrella are muscular fibres, which run, in circles, round the central chamber, and when contracted expel the water from under the umbrella, through the opening of the veil. In swimming the animal relaxes these muscles, and as the elasticity of the wall of the umbrella opens it, the water flows in through the opening of the veil and fills the central chamber. It then violently contracts its muscles, and, forcing the water out in a strong jet, drives its body through the water in the opposite direction. The veil renders the motion more vigorous by limiting the size of the stream, and it also, no doubt, helps to turn the current to one side or the other, and thus to direct the motions of the animal.

I told you, at the opening of my lecture, that some animals are as firmly fixed to one spot as an oak tree. The young of such a jelly-fish as I have just described, is an illustration of this, as it is so much like a plant that it is often found dried and pressed and forming part of a collection of sea-weeds. The egg of a jelly-fish does not hatch into a jelly-fish, or even into an animal which is to grow into a jelly-fish, as the caterpillar grows into a butterfly; but into an animal which, its whole life through, has so little resemblance to its parent that no one would for an instant suspect the relationship, if he knew nothing of the subject. The jelly-fish egg becomes a little trumpet-shaped animal, hundreds of times smaller than its parent, with no umbrella, no veil, and, after it is fully grown, no power of locomotion. When just hatched it swims about for a short time by swimming hairs, which cover its body. It soon loses these, however, and fastening itself to some object such as a stone or stick, it gives rise, like a young plant, to buds, which grow, and finally build up a beautiful branching tree-like community, with the trumpet-shaped animals at the tips of the branches (Fig. 7). After a time buds of a different kind appear on some of the branches. These grow rapidly, assume the bell-like shape of jelly-fishes, and dropping off from the branches, like fruit falling from a tree, they swim off into the water, and growing up, become animals like their grandparents, but not at all like their parents. From the eggs laid by these jelly-fishes new tree-like

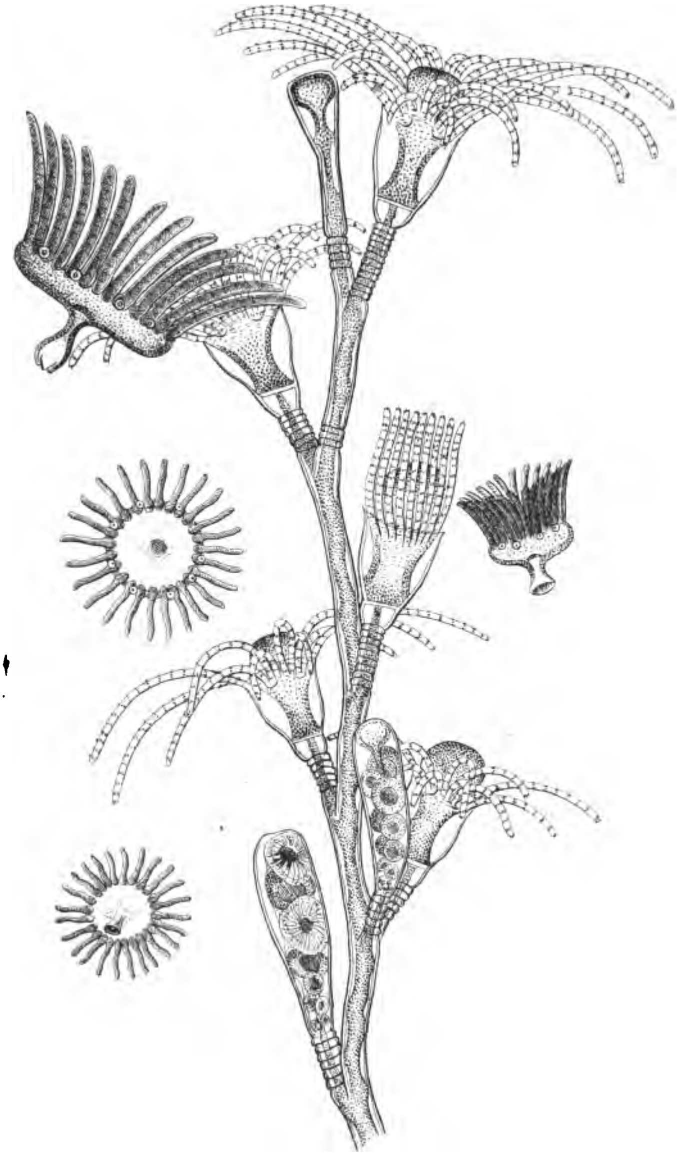

Fig. 7. A hydroid Jelly Fish, greatly magnified, showing the fixed form and the swimming form. Drawn from nature by W. K. Brooks.

communities of hydroids develop, to give rise to jelly-fish buds in their turn.

The method of swimming by pumping a stream of water seems to be quite a favorite one in nature, and we meet numerous modifications of it. One of the more interesting is presented by the Squid, or the Devil-fish. The squid has a long, slender body, and a large round head, and around the mouth a number of arms, which are used in capturing prey and crawling over the bottom. The mechanism of these arms is so peculiar that I will say a very few words about it before I speak of the animal's swimming organ. The arms are covered by rows of cup-shaped suckers, hundreds on each arm, and in each cup there is a muscular piston, which can be drawn back to form a vacuum. In order to increase the holding power of the sucking cups, a small horny saw, bent into a circle, is placed, teeth outwards, just inside the edge of each cup. In the giant squid, which grows to a length of fifteen or sixteen feet, the cups are several inches wide, and as there are ten arms, with several hundred cups on each arm, their grasping power is very great. Few animals, except a sperm whale, could break from the grasp of such an animal, or tear it from its hold upon a rocky bottom.

The swimming organ of the squid, however, is something quite different from these grasping arms, and is a sort of loose jacket around the body, open at the neck. In order to understand the form and mode of action of this swimming jacket, suppose that my body and limbs, as I stand with my arms at my sides, represent the body of a squid, and my head and neck the same parts of the squid. (Figs. 8, 9.) Now suppose my whole body up to my neck to be placed in a loose rubber bag, pointed at one end, and open around the neck, and suppose my body to be fastened to the bag along the middle of my back. If, immersed in water, I push on the inside of the bag with my hands and stretch it away from my body, the water will, of course, run in around my neck, and it will be driven out again by the elasticity of the bag as soon as I remove the pressure. The jacket of the squid is worked by the muscles which compose it, not by hands, but otherwise it is fairly represented by this model.

The gills of the squid are on the sides of the body inside the jacket, and this is primarily a respiratory organ for pumping water to and away from the gills, but a slight modification turns it

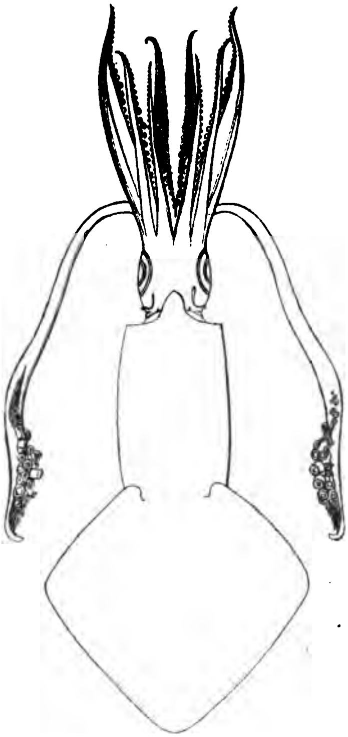

Fig. 8. Adult Squid, much smaller than life. Copied from Verrill.

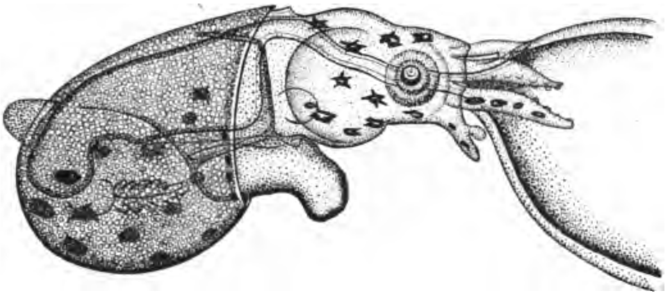

Fig. 9. A very young Squid, showing the jacket and siphon; greatly magnified. Drawn from nature by W. K. Brooks.

into an efficient organ of locomotion. Suppose that having fastened my body into the rubber jacket, I cut, in a circle of stiff leather, a little larger than the opening of the jacket, a hole to fit my neck, and fasten the leather water-tight around my neck, as a flat horizontal collar, and then tuck the edges of the collar down into the mouth of the jacket. Now when I expand the jacket the water will pass into and fill it, between its edge and the edges of the collar, but when I remove the pressure the collar will act as a valve and will be pushed out against the jacket by the water, preventing the escape of the latter. If now I make a small hole under my chin and fasten a short rubber hose and nozzle to it, the elasticity of the jacket will drive a powerful stream through it, and under water I could use this stream to drive my body backwards through the water, or by pointing the nozzle a little to one side or the other I could guide my course a little. The squid has a fleshy collar around its neck, essentially like the imaginary one of leather, and under its head there is a movable spout or nozzle, called the siphon, by which it can turn the stream of water to one side or the other. The water flows to the gills through the large orifice around the edge of the jacket, but, as it is discharged through the very small siphon, the jet of water is sufficiently powerful to drive the animal backwards with great rapidity.

Fig. 8 is a view of a full-grown squid, and Fig. 9 is a side-view of a very young one, copied from a drawing which I made some years ago from a specimen which I took, alive, out of an egg. As the very young squid is transparent, the collar and siphon can be seen through the transparent jacket, and the relation of these parts will therefore be readily understood from this figure. The large mass at the right in this figure is the yolk of the egg, fastened like a nursing bottle near the animal's mouth.

In a marine animal known as *Salpa*, which is often met with swimming at the surface of the ocean, we find another modification of the same mode of motion by pumping water. (Fig. 10.) Salpa is shaped something like a small barrel with an opening guarded by valves at each end. One set of valves opens inwards, and the other outwards. The wall of the barrel is elastic, and the barrel hoops are represented by a number of muscular bands which run around it. In swimming the animal contracts these hoops and empties the barrel. The muscles are then relaxed, and as the elasticity of the walls expands the barrel the water flows in and fills it.

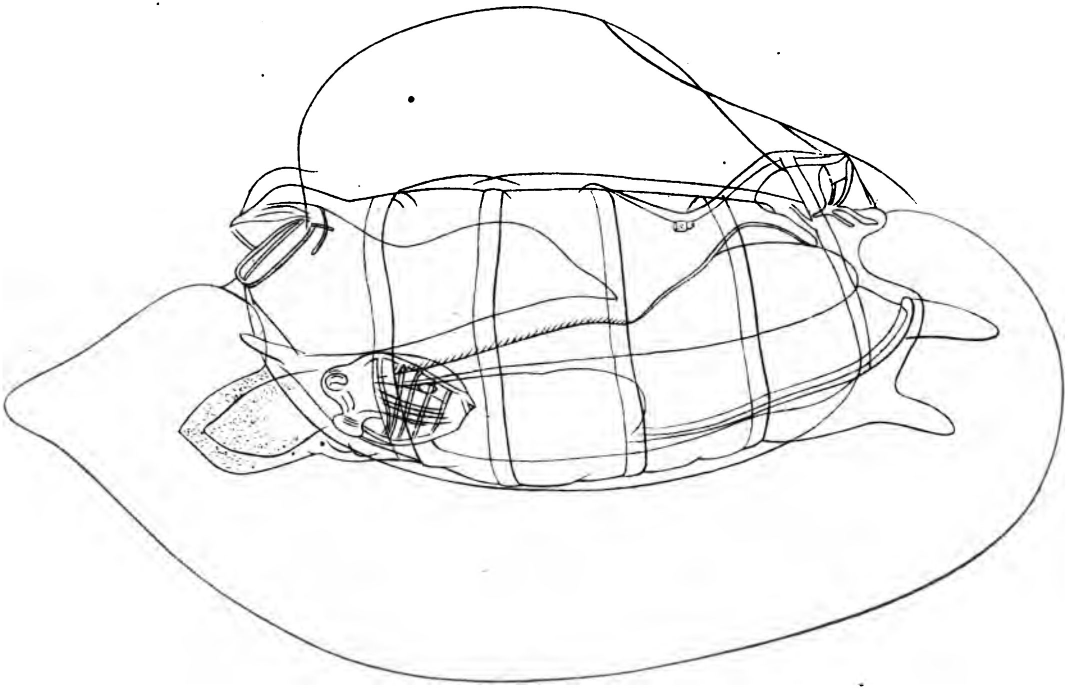

Fig. 10. A side view of Salpa, showing the muscular hoops around the barrel-like body; slightly magnified. Drawn from nature by W. K. Brooks.

As the water flows in at one end and out at the other, this pumping action drives the animal along through the water.

A comparison of Salpa with closely related animals shows us that the parts which effect the very peculiar mode of locomotion in Salpa, and which are fitted especially for this use, exist in allied animals in a simpler shape, and have simpler work to do. Whereever we are able to study in the same way any of the other contrivances by which motion is produced in animals, we meet with the same history. We may state, as a general truth, that wherever we find any part of the body of an animal especially fitted for some peculiar purpose, careful study will show us the same part in a simpler form and doing a simpler sort of work in some closely related animal. The cilia which row the slipper animal or the snail larva through the water, and which, at the same time, sweep food into the mouth, are almost exactly like the cilia which in many other animals simply set up food-currents in the water, but have no locomotor function. The pumping jacket and siphon of the squid are only a slight modification of the gill-chamber of a snail, but in the snail the gill-chamber is not an organ of locomotion, but is simply a pump to keep the breathing organs supplied with fresh water. What can be more different from each other than a digging foot for burrowing in the mud, and an organ of flight; and yet in certain clams a slight change in the burrowing foot has actually converted it into an apparatus by which the animal is enabled to make short leaps through the air.

An ordinary clam or a fresh-water mussel has so little power of motion that very careful observation is necessary to discern that it moves at all. It lives almost buried in the mud or sand, and seems to be pretty firmly planted; but if you have looked carefully at a clam at home in the sand, you will have noticed that it lies at the end of a long, shallow furrow. Careful watching will show that this furrow is formed behind the animal as it slowly plows its way along.

When the clam is opened, a tough, fleshy, tongue-like organ,—the foot, is found inside the shell under the soft body. The foot is not supported by bone, but is a soft mass of muscles something like a man's tongue. Like the tongue it can change its shape, bending from side to side, and becoming long and slender and pointed, or short and thick. It is hung inside the shell by four stout muscles, which form a sort of sling for the foot, and are attached to the inside of each shell near its ends. When the clam wishes to move it relaxes these four muscles, which are known as the foot-retractor muscles. Certain other muscles of the foot then contract until it becomes long, thin and pointed. The point is now protruded from between the edges of the opened shell, and is worked along into the sand until it is fully extended. It then changes its shape. The tip which has been thin and sharp now swells out, and acts as an anchor, by which the animal is firmly fastened into the sand. The foot-retractor muscles now contract. If the tip of the foot were free it would be pulled into the shell, but as it is fastened into the sand, the retractor muscles, instead of pulling the foot back, draw the whole body and shell through the sand up to the tip of the foot. This then changes its shape once more, and becomes thin and spade-like; and the retractor muscles relaxing again, it works its way forwards into the sand. Then changing to an anchor once more, it serves as a fixed point to which the retractor muscles again drag the body and shell. The sand is very heavy, and this plowing method of locomotion is necessarily very slow, but it is plain that if the animal were to perform the same motions in water, with sufficient rapidity, it might swim a little, since the expanded tip of the foot would be resisted by the water, and would take hold exactly as it does in the sand.

Many clams do swim a little in this way, jerking themselves for short distances through the water by violently pulling back the extended foot. In one of our small marine clams, *Yoldia,* the foot is slightly changed to fit it for this new use. The tip is split vertically, so that the halves may be spread apart like an open book, or they may be folded together. In swimming, the animal shuts the tip of its foot together, and after extending it to its full length, opens the tip. Then violently contracting its retractor muscles, it jerks its foot back into the shell, at the same time darting forwards through the water. The swimming Yoldia may be compared to a man swimming by means of an umbrella which he closes and pushes forwards, and then opening it, pulls it towards himself. The locomotor power of Yoldia is so highly developed that it is not only able to swim about in the water, but also to make leaps of eight or ten times its own length through the air, and it might be appropriately called the "flying clam." The resemblance between an ordinary burrowing clam and the flying clam is so complete that careful study would convince any one that the latter is only an ordinary burrowing clam which has been fitted for a swimming life by a slight change which has converted its digging foot into a swimming organ.

I have now sketched very rapidly some of the changes through which an ordinary swimming clam like Yoldia might be formed from an ordinary burrowing clam. I will ask you to take my word for it that careful study of any other adaptation of an animal to its surroundings would lead to the same result: the discovery of the same part in a simpler form and doing simpler work in related animals. This fact, with many others which I have no time to present to you at present, has convinced many thoughtful students of nature that the ingenious devices and efficient machinery which we meet everywhere in nature, fitting animals for their life, and adapting them to their surroundings, have actually been produced by the slow change and improvement of the simpler parts of their ancestors. Now is this conclusion an explanation of these adaptations? For my own part I fully accept the conclusion, but so far is it from being an explanation, that a very little thought will show that it is nothing of the kind. Even if I could do, what is quite impossible, and bring with me and show you a digging clam which was undergoing the change into a swimming Yoldia, I should simply show you a change. The exhibition of the change would not be an explanation of it. An obscure or complicated or unfamiliar change is *explained* by pointing out its resemblance to something which is more familiar or more easy to understand. If I can show you that the change of an ordinary Tunicate into a form like Salpa, or the change of a digging clam into one which is fitted like Yoldia for swimming, is matched by a change with which you are perfectly familiar, I shall then have given an explanation of the origin of the swimming machinery of Salpa or of Yoldia. I have no hope of getting to the bottom of the subject, or of giving a complete explanation of this or anything else, but I do hope to show you that it is no more incomprehensible than things which are as familiar to you as the falling of an apple. To do this I shall be compelled to talk a little on things which may not at first seem to have much to do with the subject. I must ask you to pay careful attention and trust me to bring things together before I close.

If left to themselves all living things would tend to increase with marvellous rapidity. No living thing is left entirely to itself, for the world is crowded, and every plant and every animal has to work for its living and fight for its place. Those which fall a prey to enemies or are crowded out by competitors are always much more numerous than those which flourish and live their lives through. It is clear that if every acorn or beechnut grew up into a forest tree the whole earth would be covered in a few generations, and all other trees and plants would be crowded out. It is plain, too, that if each one of the millions of eggs laid each year by each female codfish were to live and develop into a full-grown fish, the whole ocean would soon be filled with codfish. A little examination will show that this is true of all animals and plants, that the oak and the codfish are not exceptional, but that the slowest breeders tend to increase at such a rate that they would soon cover the whole earth if they were left to themselves.

A young lion's chance of growing up and living through its natural life is unusually favorable. The strong parental instinct leads both lion and lioness to guard and protect the young. As only two or three young are born at a time, these are sure of ample care and attention from their parents until they are able to shift for themselves. The great strength of the full-grown lion, added to the care and education which it receives from its parents, ought to fit it for holding its place in the world and for living out its natural life, as well as for rearing its young and giving them the same favorable start. We should therefore expect to find the number of lions which grow up and have children about as great as the number which are born, but nothing could be further from the truth. Some years ago, when time hung heavily on my hands, I set myself the following problem, partly from my interest in the subject and partly as a puzzle. If a single lion and lioness had been placed on the earth four thousand years ago, had lived for thirty years, and each year, from the tenth to the twentieth, had given birth to two young; if each of these young had lived for thirty years, and if each pair had borne two young annually for the ten years of their prime, and so on; if no lion had ever died from accident or hardship, but all had lived out their natural life, what would be the number of lions in the present generation? I am afraid to give you the answer, but you can figure it out for yourselves if you choose. I will only say that the lions of this generation would fill up the whole ocean and cover the whole earth, and that they would have to stand upon each other, layer upon layer, until they formed a ball hundreds of thousands of miles in diameter, with the earth like a little core in the centre, and the moon buried deeply under the surface. This case shows that even the slowest breeders would soon stock the entire earth if all the individuals which are born should grow up to maturity.

It is plain then that the world is overstocked, and that each animal must work and fight for existence. Every living thing finds itself at birth face to face with the problem how to make a place for itself in this crowded world; how to escape its enemies and vanquish its competitors; how to secure its proper share of food and air and standing room, for itself and for its children. Man is a living thing, and he is no exception to this universal rule. We find ourselves thrust without our consent into a crowded world, where food is scarce and employment hard to find. Other mouths are open to snatch our share of food, and other hands are stretched out, eager to do our work and to crowd us out of our places. Each one of us is constantly brought face to face with the question: How shall I distance my competitors and get and hold on to my share of the necessaries and comforts of life? How shall I make a place in the world for myself and my children? Every moment each of us finds this vital question staring him in the face, and I think that most of us have recognized that this is the true answer: *Make yourself a little different from your neighbors.* We may never have put it into these words, and they may not seem very clear at first, but you will all agree with me that just so soon as a man learns to do for his neighbors some useful thing which they cannot do for themselves, or learns to do his work better or more rapidly or more easily than his competitors, that man need have no fear of the struggle for existence, until his competitors overtake and pass him. It makes no difference what the useful thing is—making shoes or curing the sick; the man who can do his work better or more cheaply than his neighbors may, with health and industry, always demand in return, contributions from their shares of the necessaries and conveniences of life.

How is it that hundreds of thousands of people are able to live upon a few square miles, here in Baltimore, in health and comfort, while a few scattered savages are barely able to preserve life upon an area of hundreds of miles in the fertile plains of South America or of the West? How is it that there is always room here for more; that our children grow up and find places for themselves, and that scarcely any one actually dies of want, while death from starvation and exposure is not at all unusual among savages? Training is the explanation. One savage is hardly different from another, and each is as well able as his neighbors to supply his own wants of all kinds; while with us one man is a farmer, another a merchant; one learns a trade and another studies a profession. Each one prepares himself, by long training, to do for his neighbors some one useful thing which they cannot do as well for themselves, and in this way to work out and hold fast to a place in the world. Every year this difference between man and man grows greater, and it is due to this, and to this alone, that our country is able to support in comfort a great and growing community, instead of a few scattered and struggling savages.

Now what is true of man in this particular is true of every other living thing: there is only one way for any of them to escape competition and work out a place for itself in the world; and this way is for it to become in some way slightly different from its competitors. That the amount of life which the earth can support increases as the diversity of the forms of life increases may be shown by an illustration. Suppose that a limited area, an island for instance, is peopled by a race of farmers, and that each farmer is also his own mechanic, making and repairing his own tools, building his own houses, and spinning his own clothing, as well as cultivating his land. Let this farming community increase until all the land is occupied, and each person has only enough to supply his own wants. Now how shall we find room for any more people in the island, after all the room is occupied? By simply dividing the community into two classes, mechanics and farmers. As the farmer can now have his house and clothing made by others, he can give all his time to the cultivation of his land, and he will soon become more completely acquainted with his business than he could possibly have been when half his time and attention was given to other subjects. As his tools and implements are now made by a man who has given time and study to the subject, the farmer can do better work with them than he could with such rude tools as he could make for himself. We shall now have a more intelligent farmer, working with better tools, and having more time to devote to his work; and the result of this improvement in the cultivation of the land will be such an increase in fertility that the island will now readily support all its farmers and all its mechanics, with room to spare for others. We see then that if we can replace a single class of men all of whom have some knowledge of farming and some mechanical skill, by two classes, good farmers and good mechanics, we shall at the same time increase the population which the country can support. If any particular kind of plant or animal has increased until no more individuals can find places, the amount of life might be still further increased if we could put in the place of this living thing two slightly different kinds.

Now how can this be accomplished? Each plant or each animal has children like itself, but careful study shows that the likeness of children to parents is never quite perfect, but that the children vary slightly, although they as a rule resemble their own parents more than they do other animals or plants of the same kind. While the difference between parent and child is very slight, the variation may be in any direction whatever.

Suppose then that a certain kind of animal is so abundant that there is no room for any more individuals, but that one must die for each young one which grows up. Now suppose that one of these animals gives birth to a number of young, which differ slightly from the others in such a way that they are able to capture some article of food which the others cannot capture, or to reach and inhabit places which the others cannot reach, or to escape enemies which are destructive to the others, or to gain a similar advantage in some other way. It is plain that these animals will grow up and flourish, and will leave many children, and as the offspring resembles its parents more than it does other animals, these children will, as a rule, share this advantage, and the new race will therefore increase at the expense of the old unimproved form. The only way in which the latter can hold its place at all is by escaping from competition with the improved form, by itself improving in a different direction. We shall, therefore, have two slightly different races of animals in place of a single old form, and the number of individuals in these two races together may be very much greater than the greatest number of individuals of the old race.

The rate of increase in animals is so rapid that in a few generations the country will become fully stocked with both of the improved races, and all their advantage will be lost. Each of them will be in the position of a man who, at one time the acknowledged leader in his business, has lost his lead and has allowed his competitors to catch up with him. The only remedy is for each race to divide up again, and for each division to escape competition with the other by variation and improvement in a new direction. This process is going on continually among all kinds of living things, and its result is the endless diversity of life; the infinite variety of contrivances by which the wants of living things are supplied; the mechanism by which some capture their food in the air, while others are fitted for life in the water, or among the tree-tops, or on the ground, or under the ground; the constitution which fits one animal for life in the tropics and another for life in the arctic regions; the instinct which teaches one animal to find abundant food where another would starve; or the agility or cunning or skill which enables one animal to live securely among enemies to which another animal would quickly fall a victim.

It is often said that as our knowledge of nature increases, we grow in admiration and reverence for the great Cause to which all nature owes its existence. This is certainly so in this case. We find ourselves thrust without our consent into a world which is already overstocked. We find that there is no place for us without constant work; labor and bitter competition are everywhere around us. There is no escape from them. We feel that all this might have been better arranged; that the world owes us a living, and that an easy way to gain it ought to be provided. This weary struggle for life seems so bitter and so unjust that it is not strange that men should have believed, in old times, that labor is a curse laid upon man for his sins. Now-a-days, thanks to a wider knowledge of the world around us, we know that while the world does owe a living to every living thing which can find a place upon it, it owes this living only to those who show themselves worthy, by progress and improvement. Thanks to natural science we now know that far from being a curse, labor, and the competition and improvement which come from the necessity for labor, have been the means by which all the endless diversity of life upon the earth has been produced: and the one lesson which natural science teaches, above everything else, was summed up ages ago by the wise preacher in the words, "Whatsoever thy hand findeth to do, do it with thy might."